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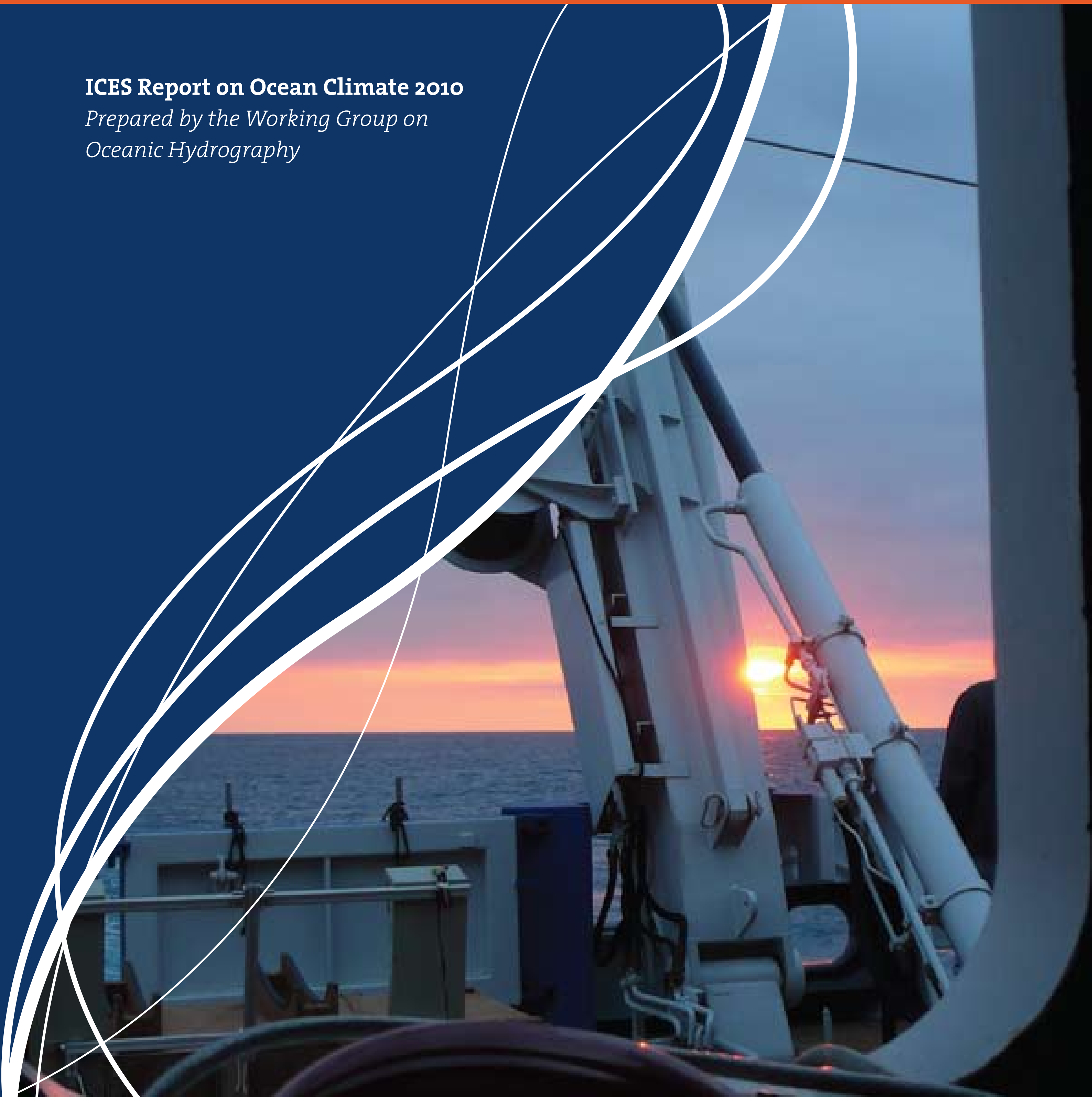
ICES COOPERATIVE RESEARCH REPORT
RAPPORT DES RECHERCHES COLLECTIVES

NO. 309 SPECIAL ISSUE
AUGUST 2011

ICES Report on Ocean Climate 2010

Prepared by the Working Group on Oceanic Hydrography



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ICES Report on Ocean Climate 2010

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Images courtesy of H. Klein, BSH Hamburg, Germany

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CONTENTS

1. INTRODUCTION

The North Atlantic region is unusual in having a relatively large number of locations at which oceanographic data have been collected repeatedly for many years or decades; the longest records go back more than a century. In this report, we provide the very latest information from the ICES Area of the North Atlantic and Nordic seas, where the ocean is currently measured regularly. We describe the status of sea temperature and salinity during 2010, as well as the observed trends over the past decade or longer. In the first part of the report, we draw together the information from the longest time-series in order to give the best possible overview of changes in the ICES Area. Throughout the report, additional complementary datasets are provided, such as sea level pressure, air temperature, and ice cover.

The main focus of the annual *ICES Report on Ocean Climate* (IROC) is the observed variability in the upper ocean (the upper 1000 m), and the introductory section includes gridded fields constructed by optimal analysis of the Argo float data distributed by the Coriolis data centre in France. Later in the report, a short section summarizes the variability of the intermediate and deep waters of the North Atlantic.

The data presented here represent an accumulation of knowledge collected by many individuals and institutions through decades of observations. It would be impossible to list them all, but at the end of the report, we provide a list of contacts for each dataset, including e-mail addresses for the individuals who provided the information, and the data centres at which the full archives of data are held.

More detailed analysis of the datasets that form the time-series presented in this report can be found in the annual meeting reports of the ICES Working Group on Oceanic Hydrography at http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=146.

1.1 Highlights of the North Atlantic for 2010

The upper layers of the northern North Atlantic and the Nordic seas were warmer and more saline in 2010 than the long-term average.

In the northeastern North Atlantic, the severe winter of 2009/2010 led to cooler ocean conditions than in previous years, but the annual mean remained above the long-term average. Severe winter ice conditions occurred in the Baltic.

In the northwestern North Atlantic, the record-high warm air temperature in winter led to very high ocean temperatures. Record-low sea ice and small numbers of icebergs were observed in the Labrador Sea.

The Nordic Seas and the outer regions of the subpolar gyre were very saline in 2010, whereas the interior region was fresher at the surface than in recent years.

Warming and salinification of deep waters continues.

1.2 Highlights of the North Atlantic atmosphere in winter 2009/2010

The NAO index in winter 2009/2010 was strongly negative, generating more extreme conditions than the record-low index observed in winter 1969/1970.

Surface air temperatures were at record-high levels over the Greenland and Labrador seas. In contrast, Northern Europe experienced unusually cold winter conditions.

Mean winds were weaker than normal across most of the North Atlantic. The dominant easterly winds replaced the more usual westerly storm track.

NORTH ATLANTIC UPPER OCEAN TEMPERATURE: OVERVIEW

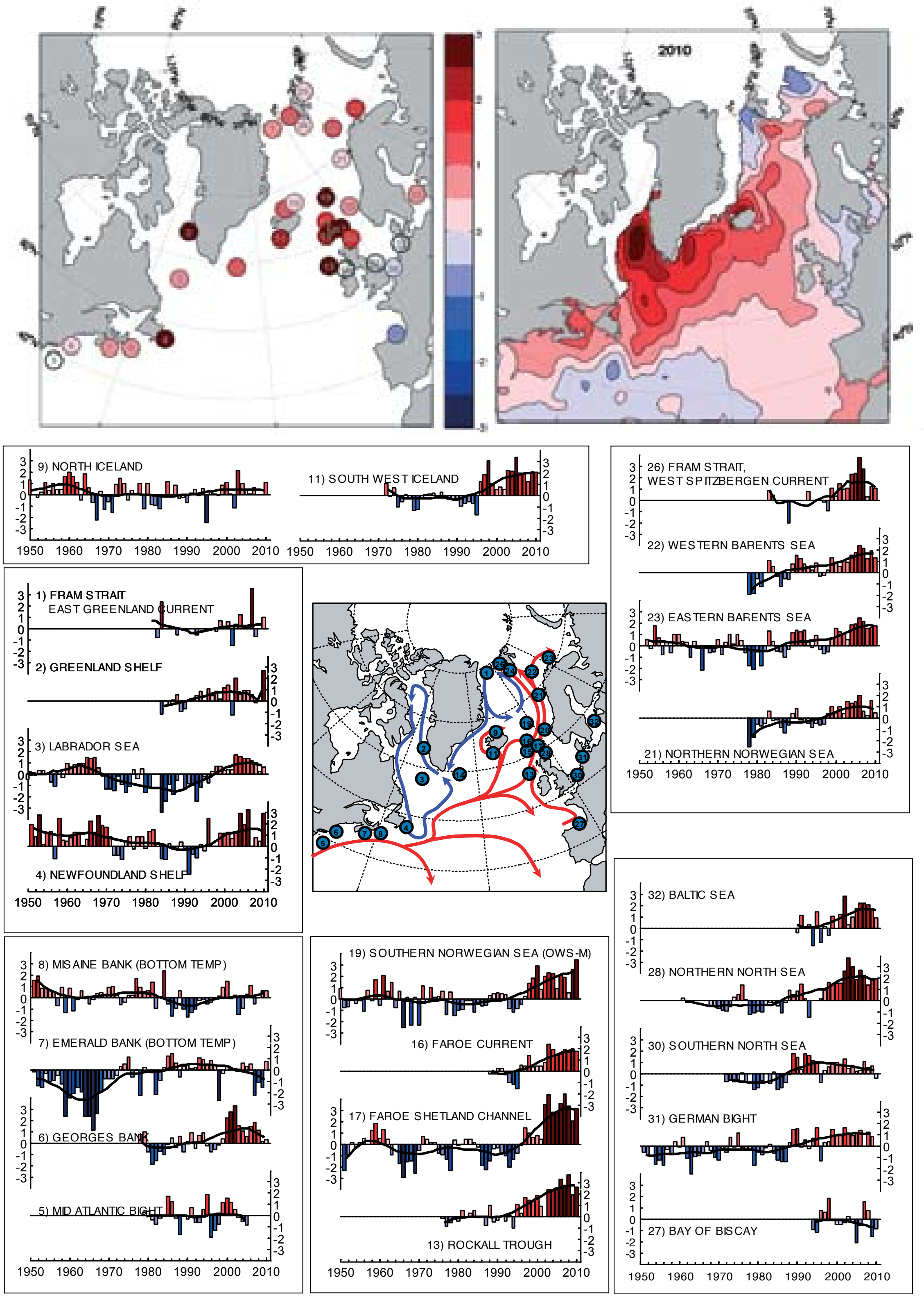


Figure 1.

Upper ocean temperature anomalies at selected locations across the North Atlantic. The anomalies are normalized with respect to the standard deviation (e.g. a value of +2 indicates 2 standard deviations above normal). Upper panels: maps of conditions in 2010; (left) data from in situ *observations; (right) 2010 anomalies calculated from OISST.v2 data (see Figure 3). Lower panels: time-series of normalized anomalies at each of the selected stations. Colour intervals 0.5ºC; reds = positive/warm; blues = negative/cool. See Figure 13 for a map supplying more details about the locations in this figure.*

NORTH ATLANTIC UPPER OCEAN SALINITY: OVERVIEW

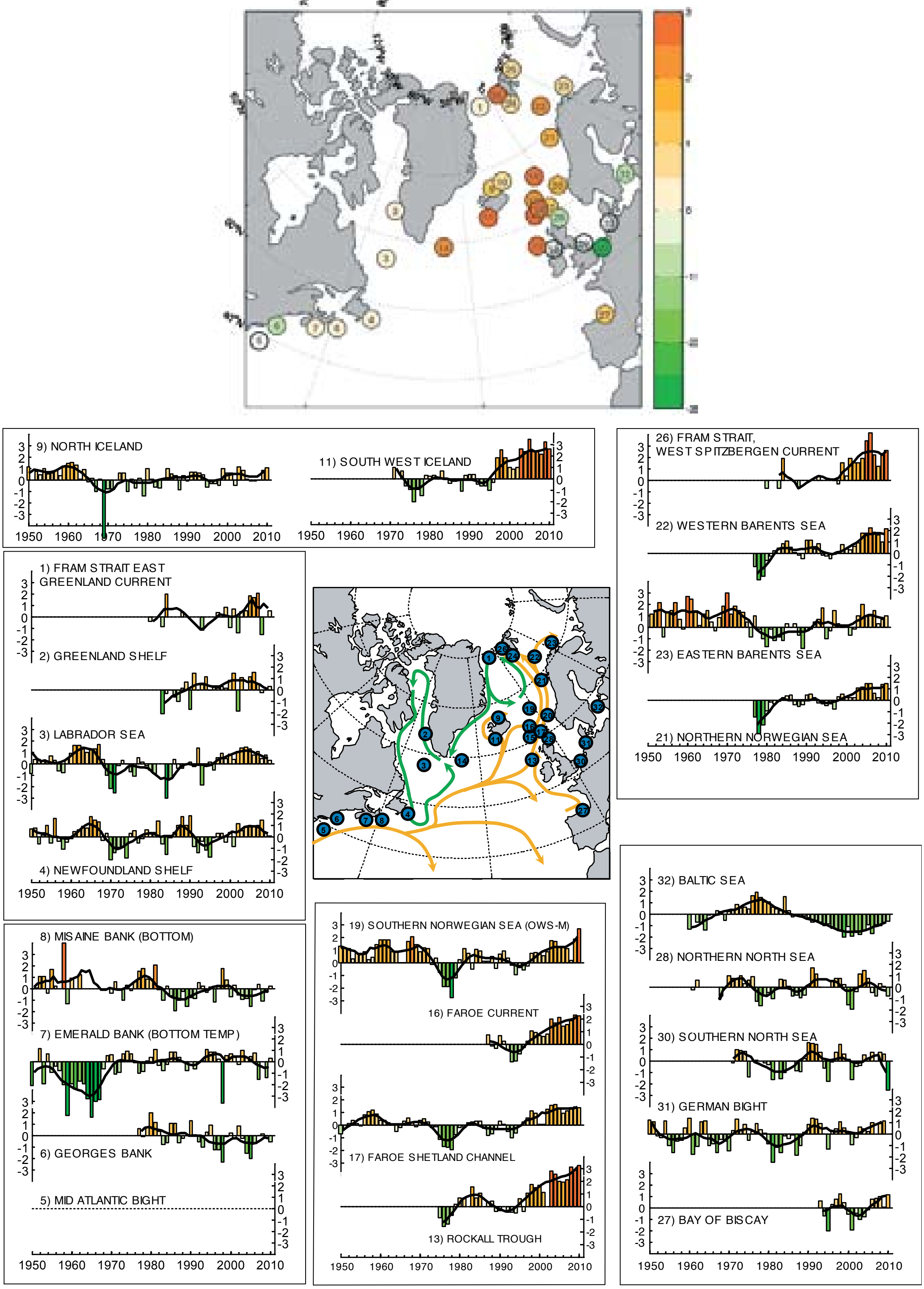


Figure 2.
Upper ocean salinity anomalies at selected locations across the North Atlantic. The anomalies are calculated relative to a long-term mean and normalized with respect to the standard deviation (e.g. a value of +2 indicates 2 standard deviations above normal). Upper panel: map of conditions in 2010. Lower panels: time-series of normalized anomalies at each of the selected stations. Colour intervals 0.5; oranges = positive/saline; greens = negative/fresh. See Figure 13 for a map supplying more details about the locations in this figure.

2. SUMMARY OF UPPER OCEAN CONDITIONS IN 2010

In this section, we summarize the conditions in the upper layers of the North Atlantic during 2010, using data from (i) a selected set of sustained observations, (ii) gridded sea surface temperature (SST) data, and (iii) gridded vertical profiles of temperature and salinity from Argo floats.

2.1 *In situ* stations and sections

Where *in situ* section and station data are presented in the summary tables and figures, normalized anomalies have been provided to allow better comparison of trends in the data from different regions (Figures 1–3; Tables 1 and 2). The anomalies have been normalized by dividing the values by the standard deviation of the data during 1971–2000. A value of +2 thus represents data (temperature or salinity) at 2 standard deviations higher than normal.

"Sustained observations", or "time-series", are regular measurements of ocean temperature and salinity made over a long period (10–100 years). Most measurements are made 1–4 times a year, but some are made more frequently.

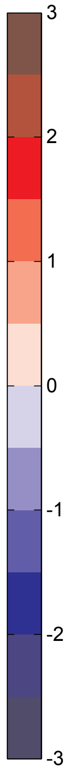
"Anomalies" are the mathematical differences between each individual measurement and the average values of temperature, salinity, or other variables at each location. Positive anomalies in temperature and salinity mean warm or saline conditions; negative anomalies mean cool or fresh conditions.

The "seasonal cycle" describes the short-term changes at the surface of the ocean brought about by the passing of the seasons; the ocean surface is cold in winter and warms through spring and summer. The temperature and salinity changes caused by the seasonal cycle are usually much greater than the prolonged year-to-year changes we describe here.

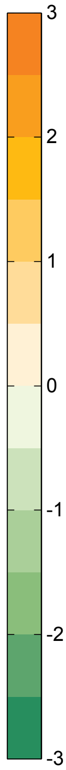
Image courtesy of N. P. Holliday, National Oceanography Centre, UK.

Tables 1 and 2.
Changes in temperature (Table 1, top) and salinity (Table 2, bottom) at selected stations in the North Atlantic region during the past decade, 2001–2010. The index numbers on the left can be used to cross-reference each point with information in Figures 1 and 2 and in Table 3. The numbers in brackets refer to detailed area descriptions featured later in the report. Unless specified, these are upper-layer anomalies. The anomalies are normalized with respect to the standard deviation (e.g. a value of +2 indicates that the data (temperature or salinity) for that year were 2 standard deviations above normal). Blank boxes indicate that data were unavailable for a particular year at the time of publication. Note that no salinity data are available for stations 5, 12, and 29. Colour intervals 0.5; red = warm; blue = cold; orange = saline; green = fresh.

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
1 (12)	0.60	-1.52	0.32	1.22	0.04	0.04	3.50	-0.75		0.99
2 (1)	1.38	-1.23	2.01	0.66	0.93	0.93	0.51	-0.19	0.04	2.75
3 (2b)	0.31	0.32	1.64	1.53	1.33	1.38	1.14	0.99	0.16	0.61
4 (2)	1.25	0.68	1.18	2.93	1.96	3.25		0.75	0.43	2.96
5 (2c)	1.20	0.54	-0.13	-0.56	-0.83					
6 (2c)	2.71	3.29	1.47	1.05	0.54	1.42	1.79	1.08	0.14	0.24
7 (2)	0.09	0.16	0.09	0.61	0.32	0.52	-2.26	-1.06	-1.54	0.81
8 (2)	-0.09	0.19	-1.48	-0.96	0.25	1.05	-0.56	-0.03	0.55	0.59
9 (3)	0.07	-1.19	2.11	0.94	0.44	0.05	0.61	-0.02	-0.02	1.05
10 (3)	-0.49	-1.04	1.54	0.39	-0.16	0.14	-0.44	0.38	0.27	0.17
11 (3)	0.73	0.47	2.22	2.15	3.34	1.95	1.89	1.19	2.08	2.06
12 (4b)	0.50	1.38	1.82	2.69	2.48	2.26	3.13			
13 (5)	0.95		2.43	2.43	2.41	3.36	2.77	3.75	1.96	2.65
14 (5b)	1.24	1.04	1.11	2.72	1.58	1.22	2.01	0.33	-0.07	1.16
15 (6)	0.86	0.89	2.75	2.43	1.53	2.58	2.34	2.62	2.45	2.15
16 (6)	0.45	0.74	2.37	1.96	1.50	1.59	1.92	1.71	2.00	1.79
17 (7)	0.40	3.47	4.33	2.80	2.80	3.60	4.40	3.38	2.02	3.11
18 (7)	1.64	2.84	3.24	2.84	2.36	2.64	2.92	3.00	3.38	4.35
19 (10)	0.80	1.94	2.27	2.20	0.85	2.14	1.90	0.49	2.57	3.44
20 (10)	0.64	1.90	1.56	0.74	0.54	1.38	1.92	0.40	1.77	0.98
21 (10)	1.00	0.42	1.49	1.34	1.45	2.02	0.60	0.24	1.57	0.49
22 (11)	0.56	1.10	0.89	1.57	1.76	2.42	2.20	1.21	1.94	1.29
23 (11)	1.16	1.04	0.48	1.80	1.86	2.39	2.10	1.49	1.59	1.71
24 (12)	-0.03	-0.26	-0.92	0.37	1.03	2.17	1.07	-0.17	0.56	0.41
25 (10)	0.35	-0.07		0.58	1.32	1.50	0.78	0.35	0.62	0.15
26 (12)	1.45	0.95	1.03	2.29	2.33	3.71	2.74	0.24	1.18	1.03
27 (4)	-0.48	-0.37	0.21	-0.31	-2.10	-0.61	1.50	0.76	-1.57	-0.92
28 (89)	1.53	2.65	3.79	3.00	1.85	2.71	2.29	1.37	1.96	1.98
29 (89)	0.49	0.69	0.84	0.68	0.17					
30 (89)	0.82	1.25	0.43	0.64	0.18	0.29	1.04	0.48	0.62	-0.41
31 (89)	0.95	1.66	1.17	0.95	1.15	1.43		1.21	0.82	
32 (9b)	1.20	2.84	0.29	0.98	1.76	2.23	2.23	2.06	1.64	0.86



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
1 (12)	0.69	-1.40	0.42	0.51	1.78	1.69	2.01	-1.54		0.48
2 (1)	1.51	-1.83	1.10	-0.02	1.20	1.52	0.56	-0.24	-0.02	0.34
3 (2b)	0.38	1.06	1.32	1.43	1.30	0.73	1.02	0.41	0.72	0.29
4 (2)	-0.88	1.17	0.54	0.96	1.00	0.92	1.00	1.46	0.33	0.04
5 (2c)										
6 (2c)	-0.29	0.84	-0.25	-1.55	-2.03	-0.75	-0.03	0.12	-0.01	-0.60
7 (2)	0.40	-0.23	1.02	0.40	0.43	0.79	-1.57		-1.41	0.34
8 (2)	0.26	-0.60	-0.96	-0.86	-1.55	-0.15	0.36	-1.10	-0.35	0.16
9 (3)	0.61	-0.48	1.14	0.81	0.02	-0.09	-0.09	-0.04	0.82	1.02
10 (3)	0.34	-0.12	0.29	0.35	0.18	0.70	0.69	0.75	0.55	0.71
11 (3)	0.83	0.97	2.54	2.37	3.40	2.37	2.46	2.08	3.17	2.56
12 (4b)										
13 (5)	1.14		2.81	2.59	2.00	1.95	2.15	3.12	2.90	3.27
14 (5b)	0.70	1.37	0.54	2.45	1.84	1.53	1.72	0.76	0.89	2.13
15 (6)	0.54	0.57	2.16	2.37	1.92	1.41	1.63	2.53	2.66	2.65
16 (6)	0.63	0.83	2.02	1.73	2.15	1.46	1.58	1.92	2.31	2.27
17 (7)	0.09	1.27	1.59	1.64	1.34	0.93	1.14	1.41	1.44	1.40
18 (7)	1.23	1.86	2.20	2.09	2.06	1.89	1.37	1.89	2.91	3.19
19 (10)	0.55	0.89	1.73	1.71	1.24	1.26	1.11	0.22	1.89	2.70
20 (10)	0.17	0.82	0.98	1.00	0.81	0.78	0.97	0.65	1.71	1.59
21 (10)	0.23	0.22	1.11	1.14	1.50	1.48	0.62	0.23	1.42	1.50
22 (11)	0.30	0.58	0.97	1.79	1.76	2.25	1.88	1.61	0.98	2.21
23 (11)	-0.72	-0.22	0.95	1.95	0.95	0.95	1.45	0.28	0.62	0.95
24 (12)	-0.17	-0.12	-0.47	0.21	1.12	1.61	1.26	0.39	0.65	0.91
25 (10)	0.40	0.14		0.74	1.48	1.70	1.30	0.90	0.80	0.88
26 (12)	1.89	1.51	1.51	1.89	3.40	4.15	2.23	1.17	2.30	2.60
27 (4)	-1.95	-0.49	-1.02	-0.77	-0.23	0.76	0.77	0.94	0.02	1.10
28 (89)	-1.93	-0.40	1.14	1.50	0.79	-0.43	-0.74	0.33	0.11	-0.75
29 (89)										
30 (89)	-1.65	-0.50	-0.39	0.52	0.18	0.72	-0.03	0.73	0.58	-2.60
31 (89)	-0.95	-0.27	0.60	0.44	0.27	1.01		0.94	1.20	
32 (9b)	-1.98	-1.48	-1.79	-1.40	-0.97	-1.70	-0.94	-1.07	-0.81	-0.68



2.2 Sea surface temperature

Sea surface temperatures across the entire North Atlantic have also been obtained from a combined satellite and *in situ* gridded dataset. Figure 3 shows the seasonal SST anomalies for 2010, extracted from the Optimum Interpolation SST dataset (OISST.v2) provided by the NOAA–CIRES Climate Diagnostics Center in the USA. In high latitudes, where *in situ* data are sparse and satellite data are hindered by cloud cover, the data may be less reliable. Regions with ice cover for >50% of the averaging period appear blank.

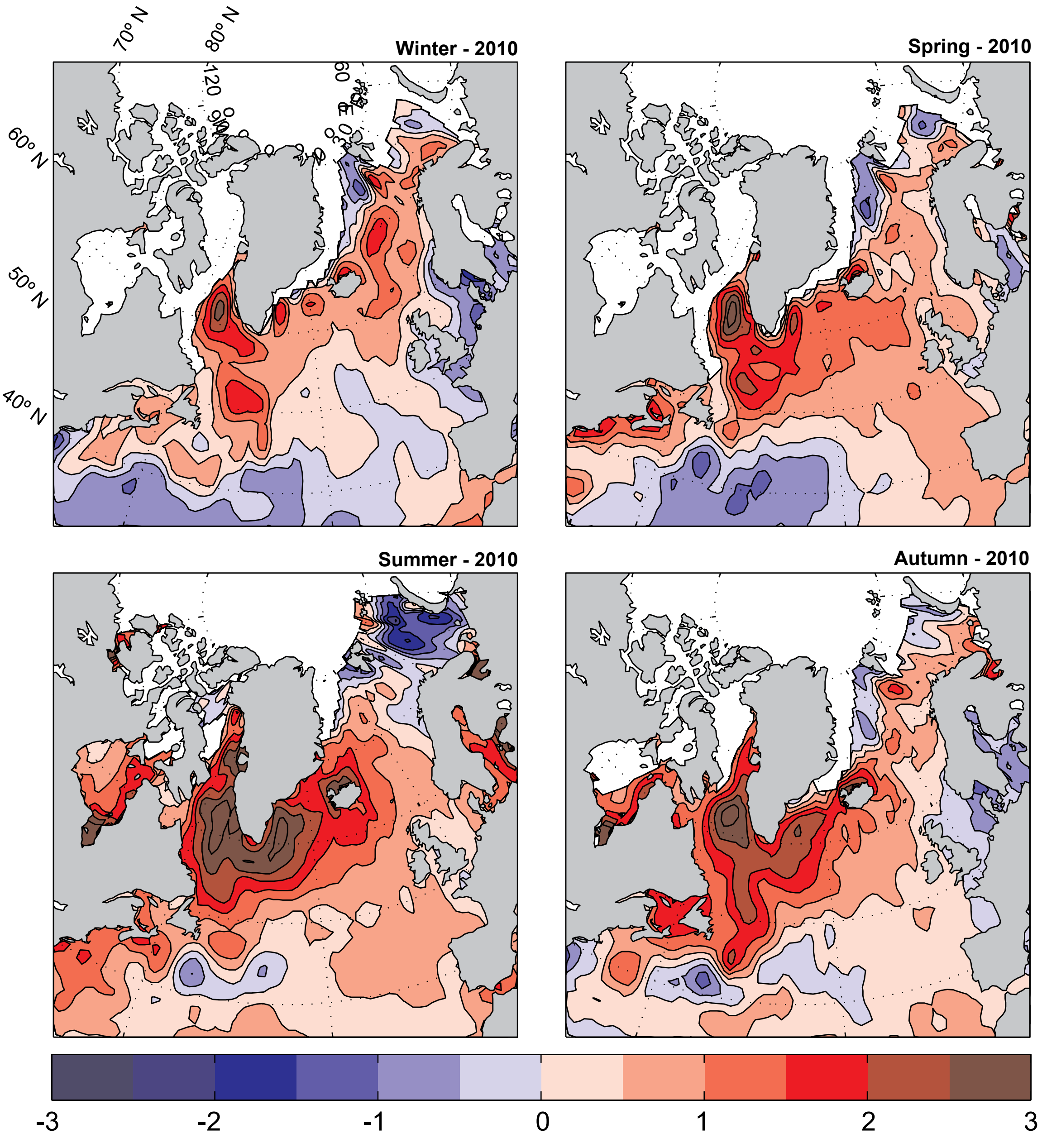


Figure 3.
Maps of seasonal sea surface temperature anomalies (°C) over the North Atlantic for 2010 from the NOAA Optimum Interpolation SSTv2 dataset provided by the NOAA–CIRES Climate Diagnostics Center, USA. The colour-coded temperature scale is the same in all panels. The anomaly is calculated with respect to normal conditions for 1971–2000. The data are produced on a 1-degree grid from a combination of satellite and in situ *temperature data. Regions with ice cover for >50% of the averaging period are left blank.*

Table 3. *Details of the datasets included in Figures 1 and 2 and in Tables 1 and 2. Blank boxes indicate that no information was available for the area at the time of publication. T = temperature, S = salinity. Some data are calculated from an average of more than one station; in such cases, the latitudes and longitudes presented here represent a nominal midpoint along that section.*

Index	Description	Area	Measurement depth	Long-term average	Lat	Lon	Mean *T*, °C	S.d. *T*, °C	Mean S	S.d. S
1	Fram Strait – East Greenland Current Section Average 3°W to shelf edge	12	50–500 m	1980–2000	78.83	-8.00	0.58	0.39	34.67	0.11
2	Station 4 – Fylla Station – Greenland Shelf	1	0–200 m	1971–2000	63.88	-53.37	3.74	1.03	33.88	0.30
3	Area 2b – west-central Labrador Sea - Section AR7W	2b	0–150 m	1990–2009	57.73	-51.07	3.73	0.45	34.71	0.07
4	Station 27 – Newfoundland Shelf (temperature) – Canada	2	0–175 m	1971–2000	47.55	-52.59	0.27	0.34	31.63	0.26
5	Oleander Section (120–400 km) – Mid-Atlantic Bight, USA	2c	Surface	1978–2000	39.00	-71.50		0.86		
6	Northwest Georges Bank – Mid-Atlantic Bight, USA	2c	1–30 m	1977–2000	42.00	-70.00	9.71	1.61	32.64	0.23
7	Emerald Basin – Central Scotian Shelf – Canada	2	Near Bottom	1971–2000	44.00	-63.00		1.20		0.23
8	Misaine Bank – Northeastern Scotian Shelf – Canada	2	Near Bottom	1971–2000	45.00	-59.00		0.65		0.16
9	Siglunes Station 2–4 – North Iceland – Irminger Current	3	50–150 m	1971–2000	67.00	-18.00	3.34	1.09	34.82	0.19
10	Langanes Station 2–6 – Northeast Iceland – East Icelandic Current	3	0–50 m	1971–2000	67.50	-13.50	1.24	0.95	34.70	0.14
11	Selvogsbanki Station 5 – Southwest Iceland – Irminger Current	3	0–200 m	1971–2000	63.00	-22.00	7.64	0.37	35.15	0.04
12	Malin Head Weather Station	4b	Surface	1971–2000	55.37	-7.34	10.57	0.46		
13	Ellett Line – Rockall Trough – UK (section average)	5	0–800 m	1975–2000	56.75	-11.00	9.21	0.22	35.33	0.03
14	Central Irminger Sea – Subpolar Mode Water	5b	200–400 m	1991–2005	59.40	-36.80	3.99	0.55	34.88	0.03
15	Faroe Bank Channel – West Faroe Islands	6	Layer between 100 and 300 m depth	1988–2000	61.00	-8.00	8.23	0.32	35.24	0.04
16	Faroe Current – North Faroe Islands (Modified North Atlantic Water)	6	Upper-layer, high-salinity core	1988–2000	63.00	-6.00	7.92	0.37	35.22	0.04
17	Faroe – Shetland Channel – Shetland Shelf (North Atlantic Water)	7	Upper-layer, high-salinity core	1971–2000	61.00	-3.00	9.57	0.15	35.36	0.04
18	Faroe – Shetland Channel – Faroe Shelf (Modified North Atlantic Water)	7	Upper-layer, high-salinity core	1971–2000	61.50	-6.00	7.85	0.25	35.22	0.04
19	Ocean Weather Station “M” – 50 m	10	50 m	1971–2000	66.00	-2.00	7.49	0.34	35.15	0.05
20	Southern Norwegian Sea – Svinøy Section – Atlantic Water	10	50–200 m	1977–2000	63.00	3.00	7.99	0.39	35.23	0.05
21	Central Norwegian Sea – Gimsøy Section – Atlantic Water	10	50–200 m	1977–2000	69.00	10.00	6.81	0.39	35.15	0.04
22	Fugløya – Bear Island Section – western Barents Sea – Atlantic Inflow	11	50–200 m	1977–2006	73.00	20.00	5.35	0.52	35.06	0.05
23	Kola Section – eastern Barents Sea	11	0–200 m	1971–2000	71.50	33.30	3.92	0.49	34.76	0.06
24	Greenland Sea Section – west of Spitsbergen 76.5°N	12	200 m	1996–2008	76.50	10.50	3.08	0.66	35.05	0.04
25	Northern Norwegian Sea – Sørkapp Section – Atlantic Water	10	50–200 m	1977–2000	76.33	10.00	3.80	0.71	35.05	0.05
26	Fram Strait – West Spitsbergen Current – Section average 5°E to shelf edge	12	50–500 m	1980–2000	78.83	8.00	2.60	0.58	34.99	0.03
27	Santander Station 6 (shelf break) – Bay of Biscay – Spain	4	5–200 m	1993–2000	43.70	-3.78	12.72	0.18	35.61	0.05
28	Fair Isle Current Water (waters entering North Sea from Atlantic)	8 & 9	0–100 m	1971–2000	59.00	-2.00	9.71	0.34	34.84	0.07
29	UK Coastal Waters – Southern Bight – North Sea	8 & 9	Surface	1971–2000	54.00	0.00				
30	Section average – Felixstowe – Rotterdam – 52°N	8 & 9	Surface	1971–2000	52.00	3.00	12.24	0.81	34.65	0.21
31	Helgoland Roads – coastal waters – German Bight – North Sea	8 & 9	Surface	1971–2000	54.19	7.90	10.10	0.72	32.11	0.54
32	Baltic Proper – east of Gotland – Baltic Sea	9b	Surface	1971–2000 (S) 1990–2000 (T)	57.50	19.50	8.57	0.86	7.35	0.24

2.3 Gridded temperature and salinity fields

A summary of recent conditions in the North Atlantic can be established using the Argo global observing system based on profiling floats. Temperature and salinity fields are estimated on a regular half-degree (Mercator scale) grid using ISAS (*In Situ* Analysis System; Gaillard *et al*., 2009), a tool developed and maintained at LPO (Laboratoire de Physique des Océans) within the SO-Argo (http://wwz.ifremer.fr/lpo/SO-Argo-France). The datasets used are the standard files prepared by the Coriolis data centre for the operational users. They contain mostly Argo profiles, but CTDs (conductivity, temperature, and depths), buoys, and mooring data are also included. Some changes with respect to the results presented in IROC 2009 (Hughes *et al*., 2010) have been introduced, as follows. The latest version, ISAS_V5.3, was used for the processing; the Argo "adjusted" data type was selected instead of the "raw" data type in IROC 2009; the reference field is the average of the 2002–2008 analysed fields (the World Ocean Atlas, WOA-05, was used in the previous report); and the *a priori* variances have been re-evaluated using the same 2002–2008 period.

Near the surface, the North Atlantic winter was anomalously cold south of the North Atlantic Current, including the eastern boundary. A warm anomaly started to develop in spring around Greenland, in the Labrador Sea, and along the western boundary. It culminated in summer, when it spread throughout the basin. The anomaly persisted, but with reduced intensity through autumn. A fresh anomaly developed in the west-central part and reached its maximum in summer and autumn. Simultaneously, waters were anomalously saline along the coasts of Norway and Greenland, and around the Labrador Sea. On average during 2010, the surface layer exhibited a positive temperature anomaly over most of the basin. This anomaly was particularly intensive (more than 1.5°C) around Greenland and along the coast of North America. In the central basin, the surface salinity revealed a fresh anomaly, which was surrounded by waters more saline than normal; the northwest boundary was particularly saline (0.3 above average). The very warm Irminger and Labrador seas, and the fresh central basin, characterize 2010 in the 2005–2010 time-series.

At 300 m, the structure of the temperature anomaly remained the same as near surface, but warm and cold anomalies there were more balanced with regard to area and amplitude. The extent of the fresh anomaly observed near surface was reduced at this depth, leaving space for a positive anomaly over most of the basin. At this level, temperature and salinity anomalies were nearly anticorrelated. At 1000 m, the influence of the Mediterranean Water (warm and saline anomaly) was increased south of 48°N and decreased north of this latitude, as was the case in 2009. At greater depth (1600 m), the Greenland Sea, the Irminger Sea, and the Labrador Sea are warming, especially at 1600 m, where this temperature anomaly is associated with higher salinity water. These features have been developing continuously since 2004.

The variations in the February mixed-layer depth (defined as the depth where temperature differs by more than 0.5°C from the 10-m value) are shown in Figure 8. In 2010, the mixed layer was particularly deep along the eastern boundary (north of the Bay of Biscay in particular) and extended zonally westwards in the basin, with a sharp south limit at 42°N. A deep mixed layer was also observed above the Reykjanes Ridge.

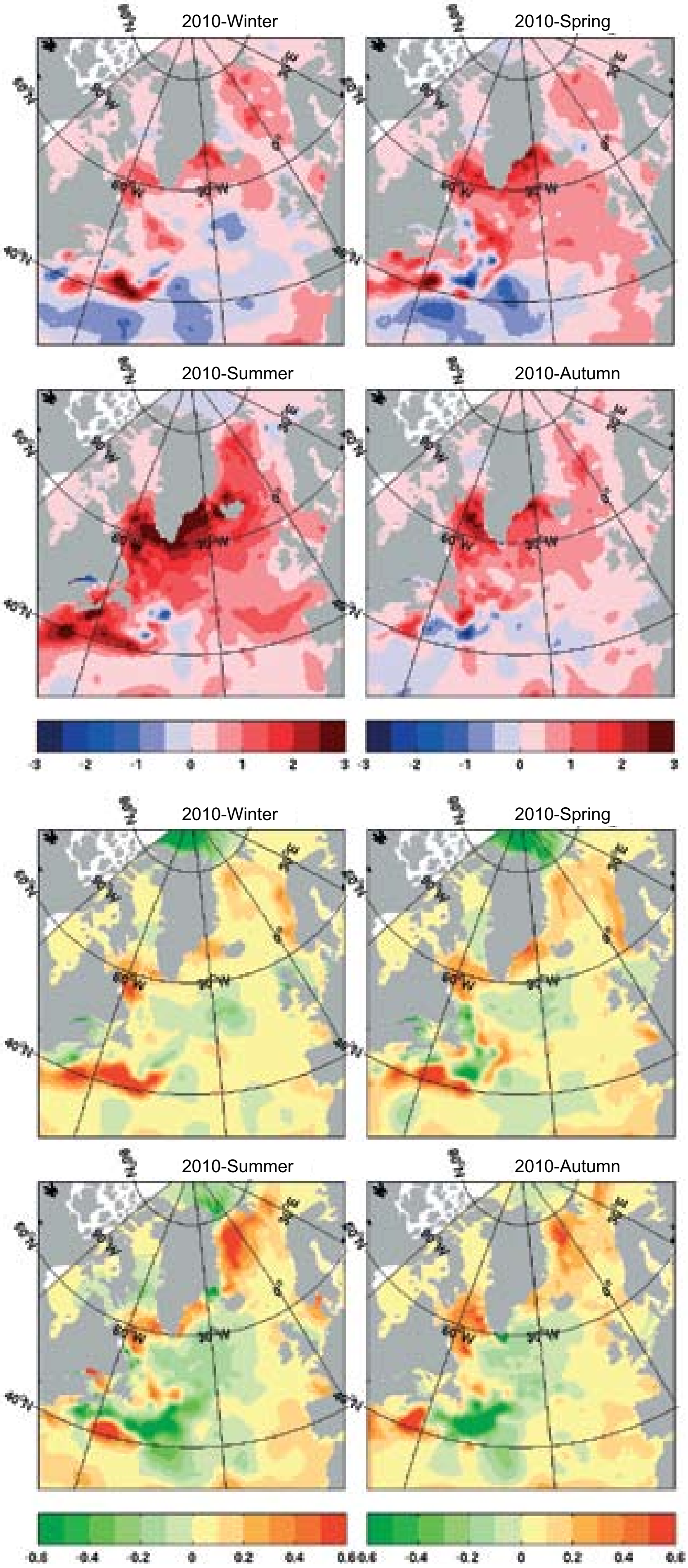


Figure 4.
Maps of 2010 seasonal temperature anomalies (upper) and salinity anomalies (lower) at 10 m depth in the North Atlantic. (Anomalies are the differences between the ISAS monthly mean values and the reference climatology, WOA-05. The colour-coded temperature scale is the same in all panels.) From the ISAS monthly analysis of Argo data.

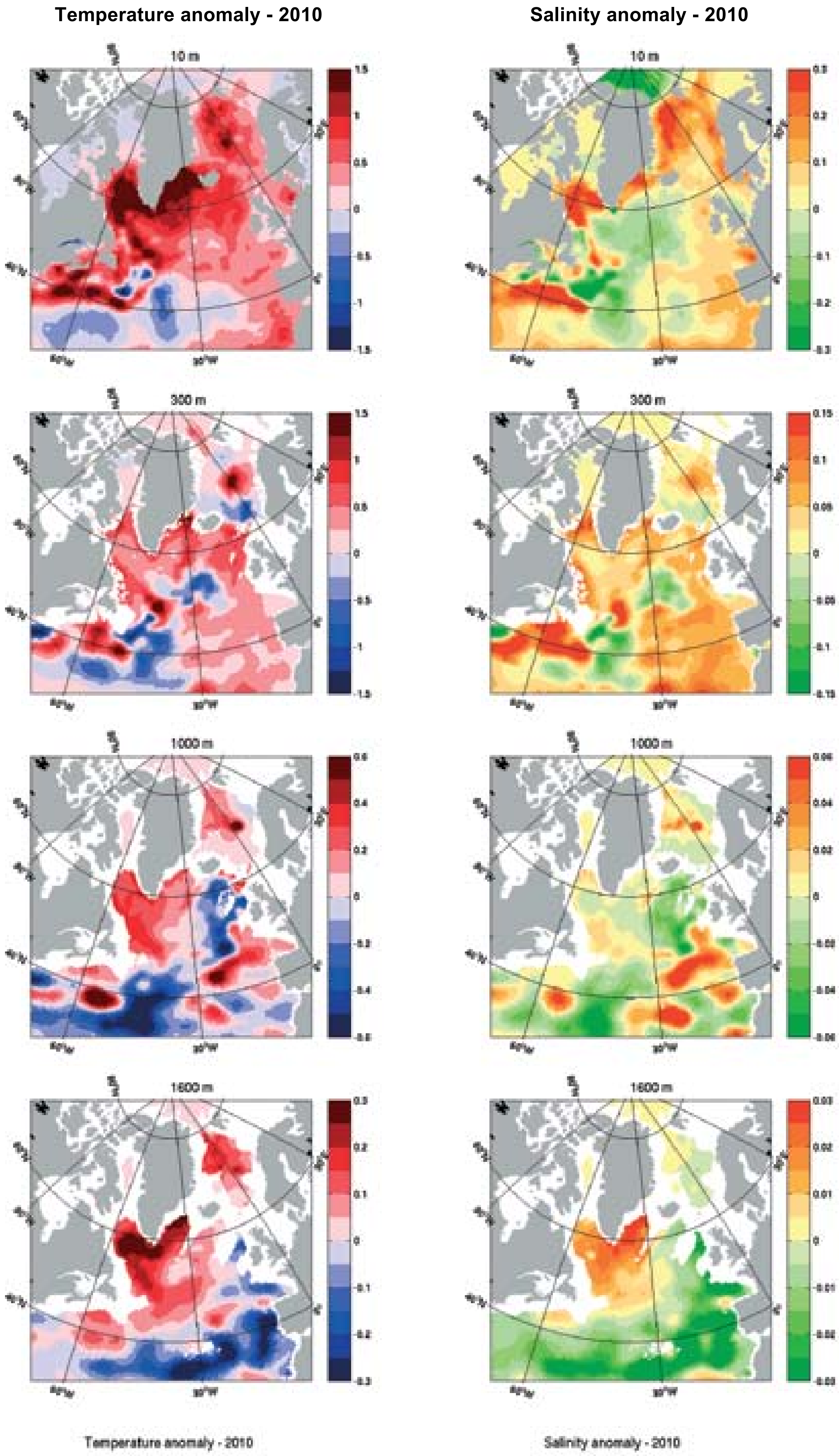
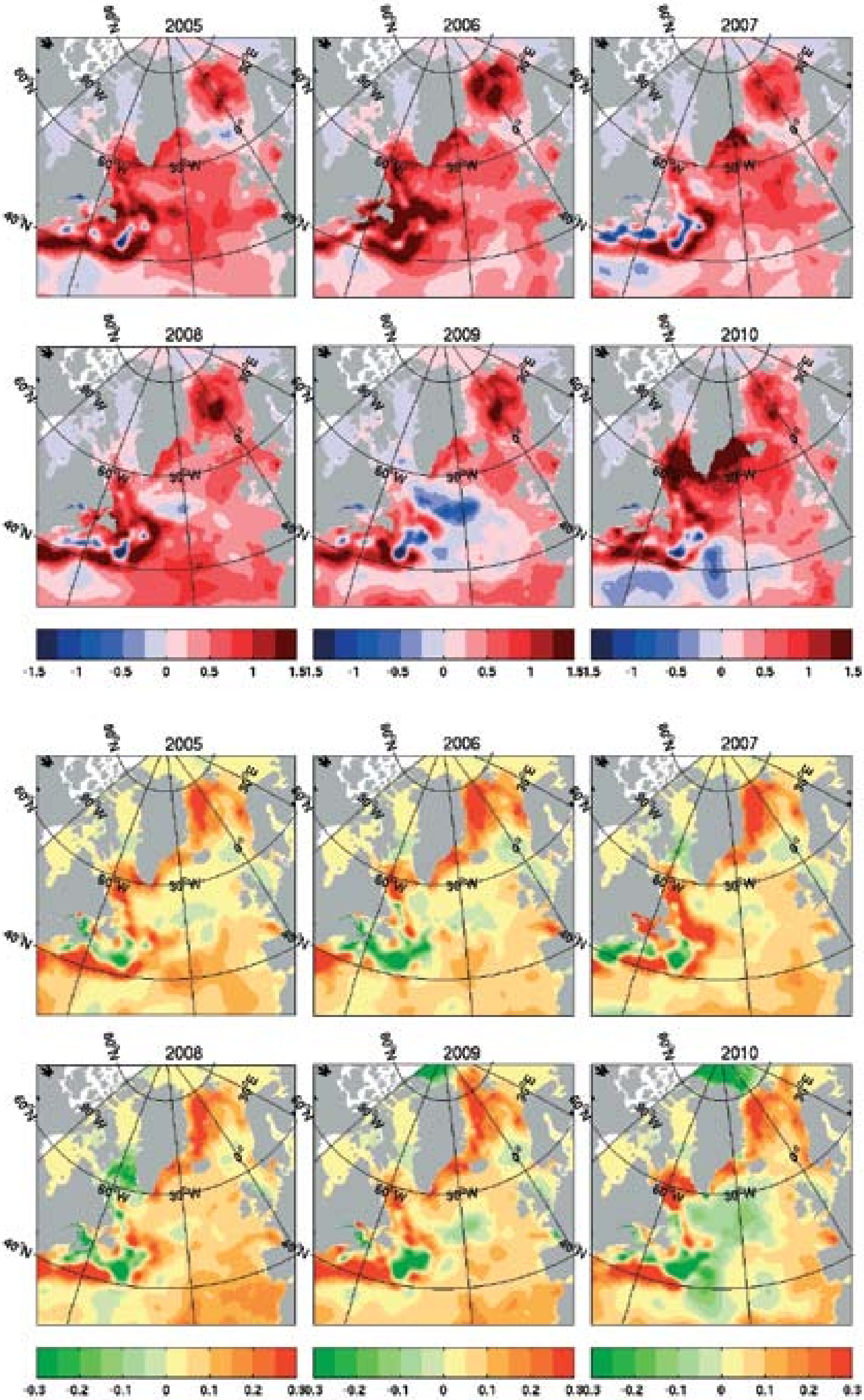


Figure 5.
Maps of 2010 annual temperature anomalies (left) and salinity anomalies (right) at 10, 300, 1000, and 1600 m. (Anomalies are the differences between the ISAS annual means and the reference climatology, WOA-05. Note the different scales for each map.) From the ISAS monthly analysis of Argo data.

__Figure 6.__
Maps of annual temperature anomalies (upper) and salinity anomalies (lower) at 10 m for 2005–2010. From the ISAS monthly analysis of Argo data.



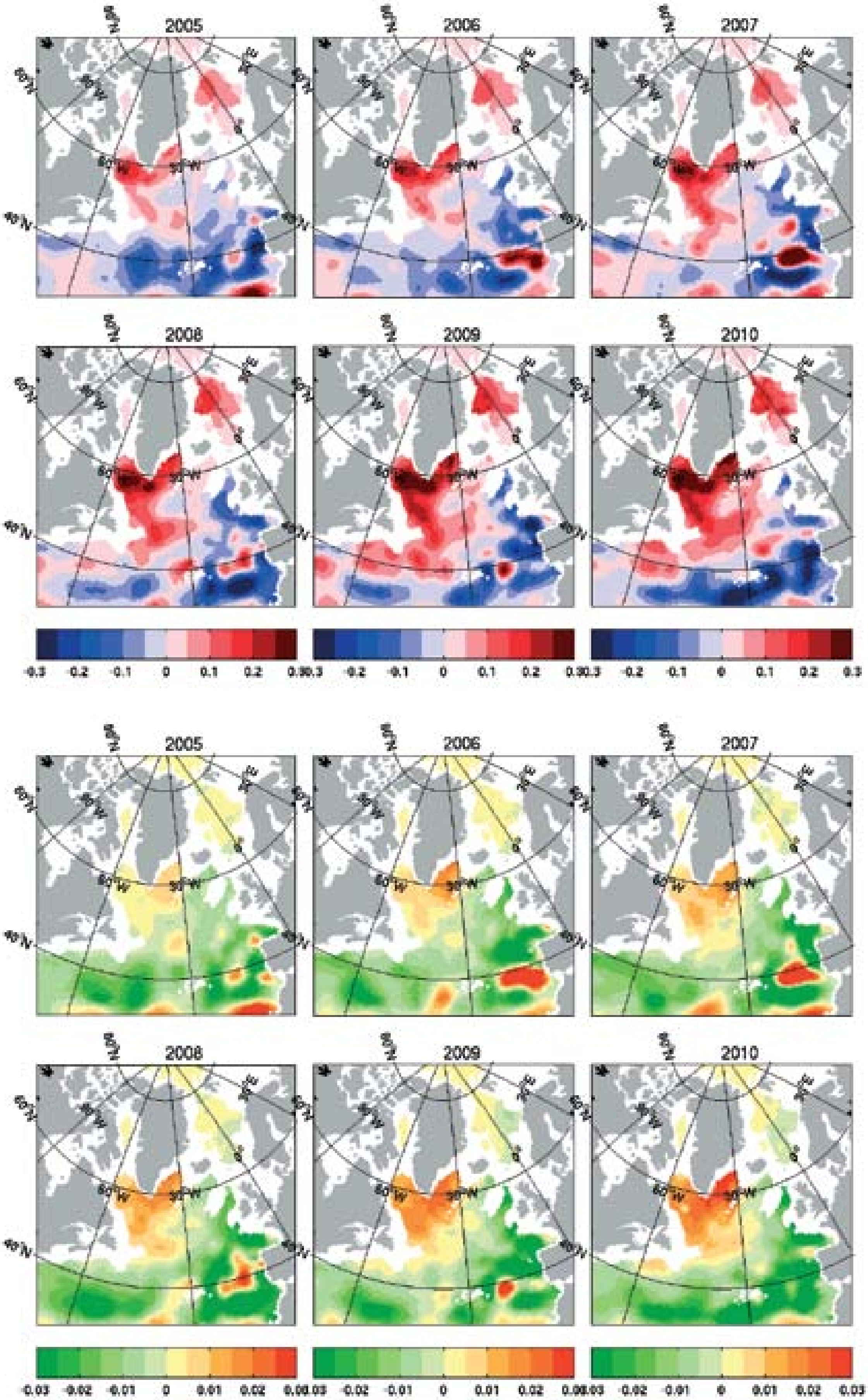


Figure 7.
Maps of annual temperature anomalies (upper) and salinity anomalies (lower) at 1600 m for 2005–2010. From the ISAS monthly analysis of Argo data.

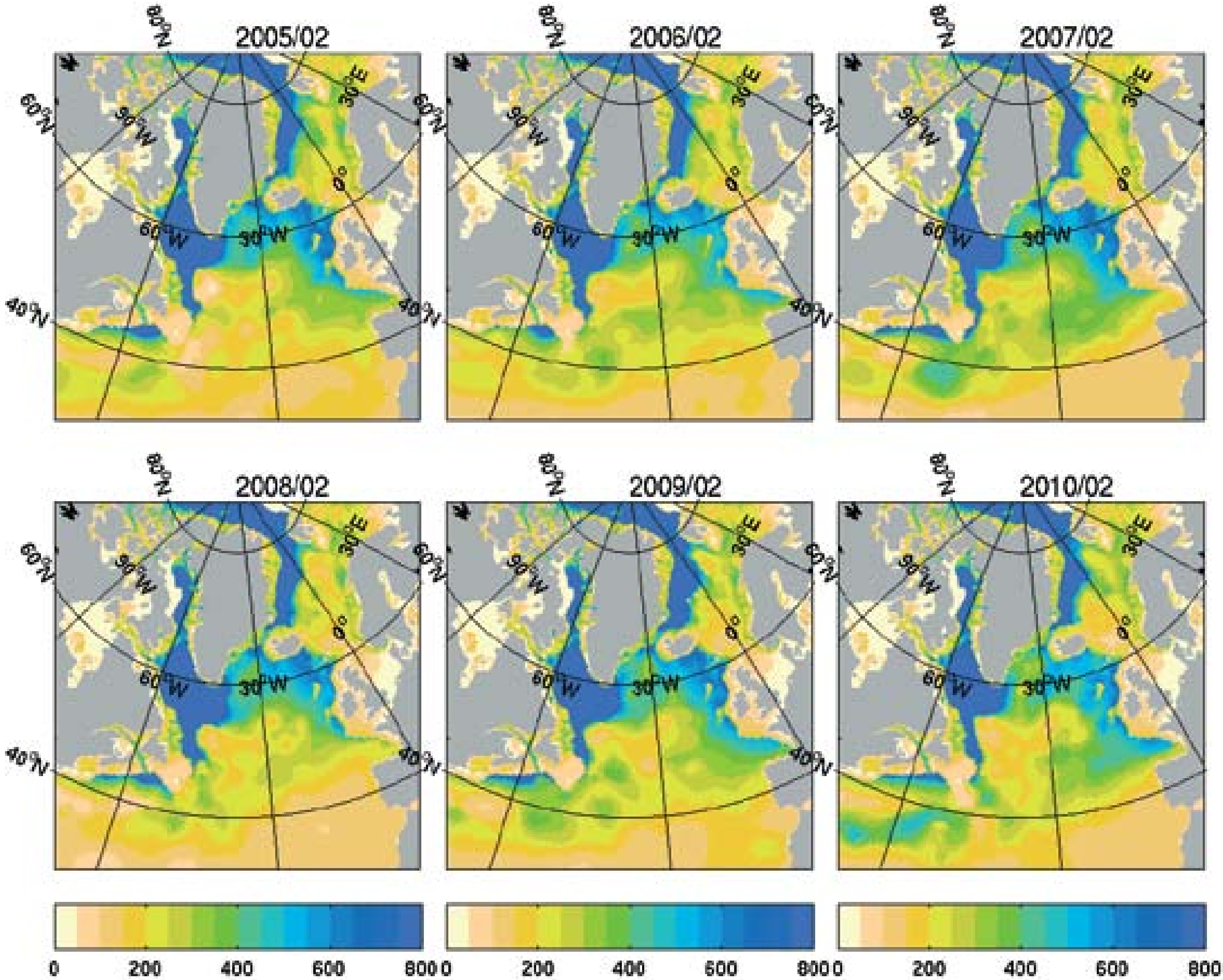


Figure 8.
Maps of North Atlantic winter (February) mixed-layer depths for 2005–2010. From the ISAS monthly analysis of Argo data. Note that the mixed-layer depth is defined as the depth at which the temperature has decreased by more than 0.5°C from the temperature at 10 m depth. This criterion is not suitable for areas where effects of salinity are important (ice melting) or where the basic stratification is weak. Therefore, results in the Labrador Sea, around Greenland, and in the Gulf of Lion are not significant.

3. THE NORTH ATLANTIC ATMOSPHERE

3.1 Sea level pressure

The North Atlantic Oscillation (NAO) is a pattern of atmospheric variability that has a significant impact on oceanic conditions. It affects windspeed, precipitation, evaporation, and the exchange of heat between ocean and atmosphere, and its effects are most strongly felt in winter. The NAO index is a simple device used to describe the state of the NAO. It is a measure of the strength of the sea level air pressure gradient between Iceland and Lisbon, Portugal. When the NAO index is positive, there is a strengthening of the Icelandic low-pressure system and the Azores high-pressure system. This produces stronger mid-latitude westerly winds, with colder and drier conditions over the western North Atlantic and warmer and wetter conditions in the eastern North Atlantic. When the NAO index is negative, there is a reduced pressure gradient and the effects tend to be reversed.

There are several slightly different versions of the NAO index calculated by climate scientists. The Hurrell winter (December/January/February/March, or DJFM) NAO index is most commonly used and is particularly relevant to the eastern North Atlantic. Following a long period of increase, from an extreme and persistent negative phase in the 1960s to a most extreme and persistent positive phase during the late 1980s and early 1990s, the Hurrell NAO index underwent a large and rapid decrease during winter 1995/1996.

Between 1996 and 2009, the Hurrell NAO index was fairly weak and a less useful descriptor of atmospheric conditions. When the NAO is weak, two additional dominant atmospheric regimes have recently been recognized as useful descriptors: (i) the Atlantic Ridge mode, when a strong anticyclonic ridge develops off western Europe (similar to the East Atlantic pattern); and (ii) the Blocking regime, when the anticyclonic ridge develops over Scandinavia. The four regimes (positive NAO, negative NAO, Atlantic Ridge, and Blocking) have all been occurring at around the same frequency (20–30% of all winter days) since 1950. These modes of variability are revealed through cluster analysis of sea level pressure (SLP) rather than examining point-to-point SLP gradients.

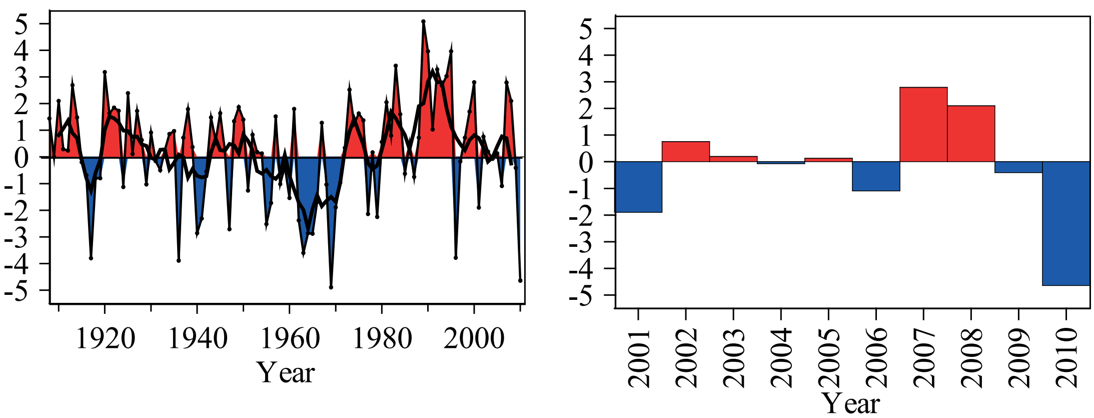


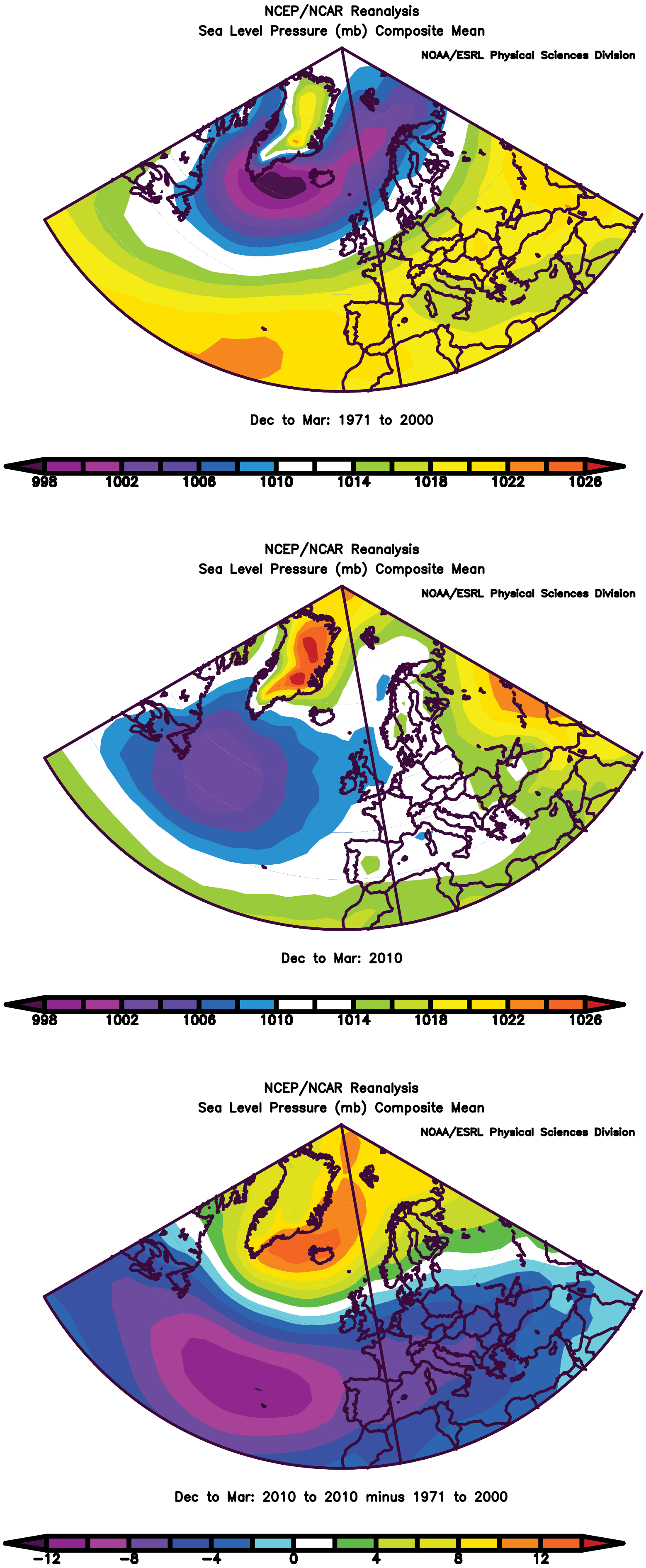
Figure 9.
The Hurrell winter (DJFM) NAO index for the past 100 years with a 2-year running mean applied (left panel) and for the current decade (right panel). Data source: http://www.cgd.ucar.edu/cas/jhurrell/nao.stat.winter.html.

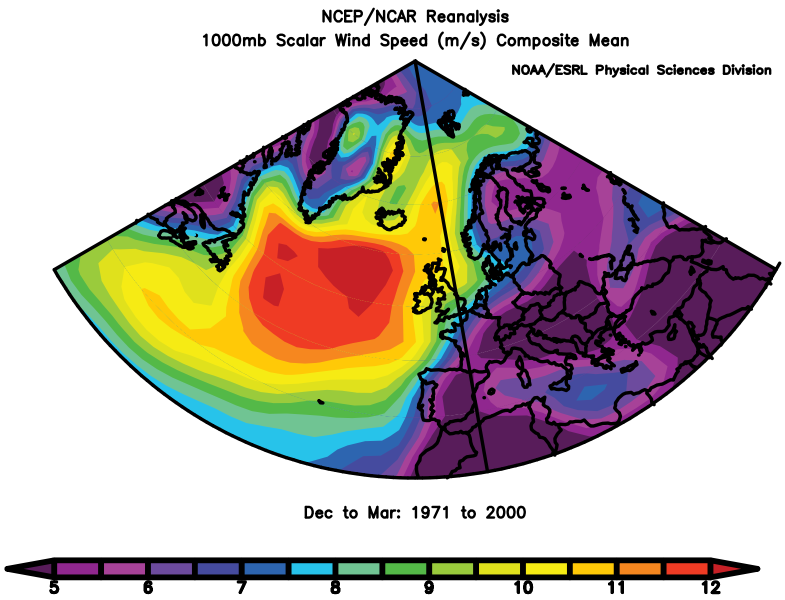
In winter 2009/2010, the Hurrell NAO index was strongly negative (–4.64; Figure 9); this was the strongest negative anomaly since 1969 and the second strongest negative value for the Hurrell winter NAO index in the record (started in 1864). The atmospheric conditions indicated by this negative NAO index are more clearly understandable when the anomaly fields are mapped. Ocean properties are particularly dominated by winter conditions, hence the inclusion of maps of SLP for winter (DJFM; Figure 10). The top panel of Figure 10 shows the winter SLP averaged over 30 years (1971–2000). The dominant features ("action centres") are the Iceland Low (the purple patch situated southwest of Iceland) and the Azores High (the orange patch west of Gibraltar).

IN WINTER 2009/2010, THE HURRELL NAO INDEX WAS STRONGLY NEGATIVE.

The middle panel of Figure 10 shows the mean SLP for winter 2010 (December 2009, January–March 2010), and the bottom panel shows the 2010 winter SLP anomaly (i.e. the difference between the top and middle panels). In winter 2010, the average SLP field is clearly different from the 1971–2000 average. Neither the Iceland Low nor the Azores High was evident. A strong average cyclonic circulation centred south of Cape Farewell and east of Newfoundland dominated the whole Atlantic north of the Azores, leading to a SLP anomaly that is strongly NAO negative in character. The figures show contours of constant SLP (isobars).

The geostrophic (or "gradient") wind blows parallel with the isobars, with lower pressure to the left, and the closer the isobars, the stronger the wind. The strength of the mean surface wind averaged over the 30-year period (1971–2000) is shown in the upper panel of Figure 11, while the lower panel shows the anomaly in winter 2010. These re-analyses demonstrate that the mean winds were stronger than normal across the southern part of the region, over the Mediterranean, in the north of the Labrador Sea, and in isolated regions west and east of Iceland. Winds were weaker than normal north of Iceland, northwest of the Azores, and in a broad band centred over Ireland, northern UK, and southwestern Norway. The band stretched from Cape Farewell to the northern Bay of Biscay across the northwest European marginal seas and continental margin up to the North Cape of Norway.





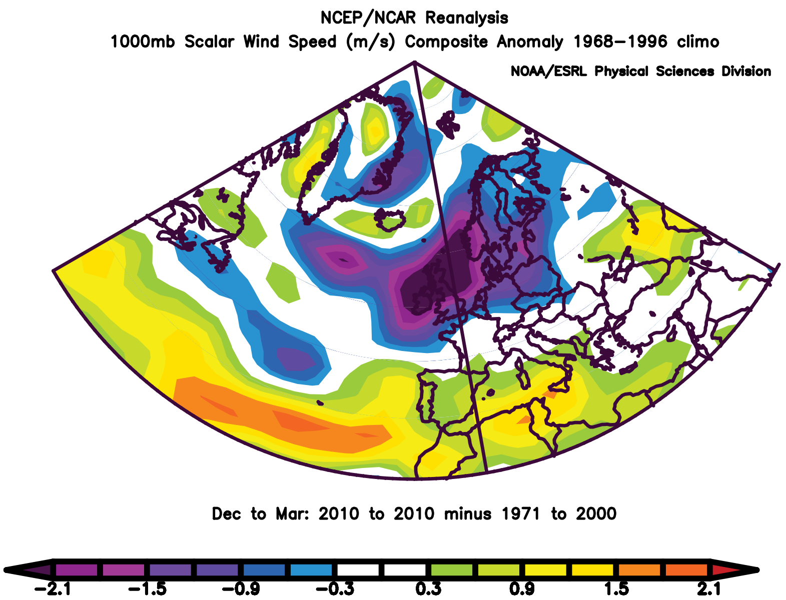


Figure 11.
Winter (DJFM) surface windspeed. Upper panel: surface windspeed averaged over 30 years (1971–2000). Lower panel: winter 2010 anomaly in surface windspeed. Images provided by the NOAA/ESRL Physical Sciences Division, Boulder, CO (available online at http://www.cdc.noaa.gov/).

Figure 10 (left).
Winter (DJFM) sea level pressure (SLP) fields. Top panel: SLP averaged over 30 years (1971–2000). Middle panel: mean SLP in winter 2010 (December 2009, January–March 2010). Bottom panel: winter 2010 SLP anomaly – the difference between the top and middle panels. Images provided by the NOAA/ESRL Physical Sciences Division, Boulder, CO (available online at http://www.cdc.noaa.gov/).

3.2 Surface air temperature

North Atlantic winter mean surface air temperatures are shown in Figure 12. The 1971–2000 mean conditions (Figure 12, top panel) show warm temperatures penetrating far to the north on the eastern side of the North Atlantic and the Nordic seas, caused by the northward movement of warm oceanic water. The middle panel of Figure 12 shows the conditions in winter (DJFM) 2009/2010, and the bottom panel shows the difference between the two. In winter 2009/2010, the central North Atlantic and Norwegian Sea surface air temperatures were near normal. The western North Atlantic and the seas off the continental margin were more than 1°C cooler than normal, as was all of northern Europe apart from Scotland. In contrast, the surface air temperature over the Irminger and Greenland seas was more than 1°C warmer than normal. Temperature over the Labrador Sea was very warm; much of the area was more than 4°C warmer than the 1971–2000 average.

SURFACE AIR TEMPERATURES WERE AT RECORD-HIGH LEVELS OVER THE GREENLAND AND LABRADOR SEAS.

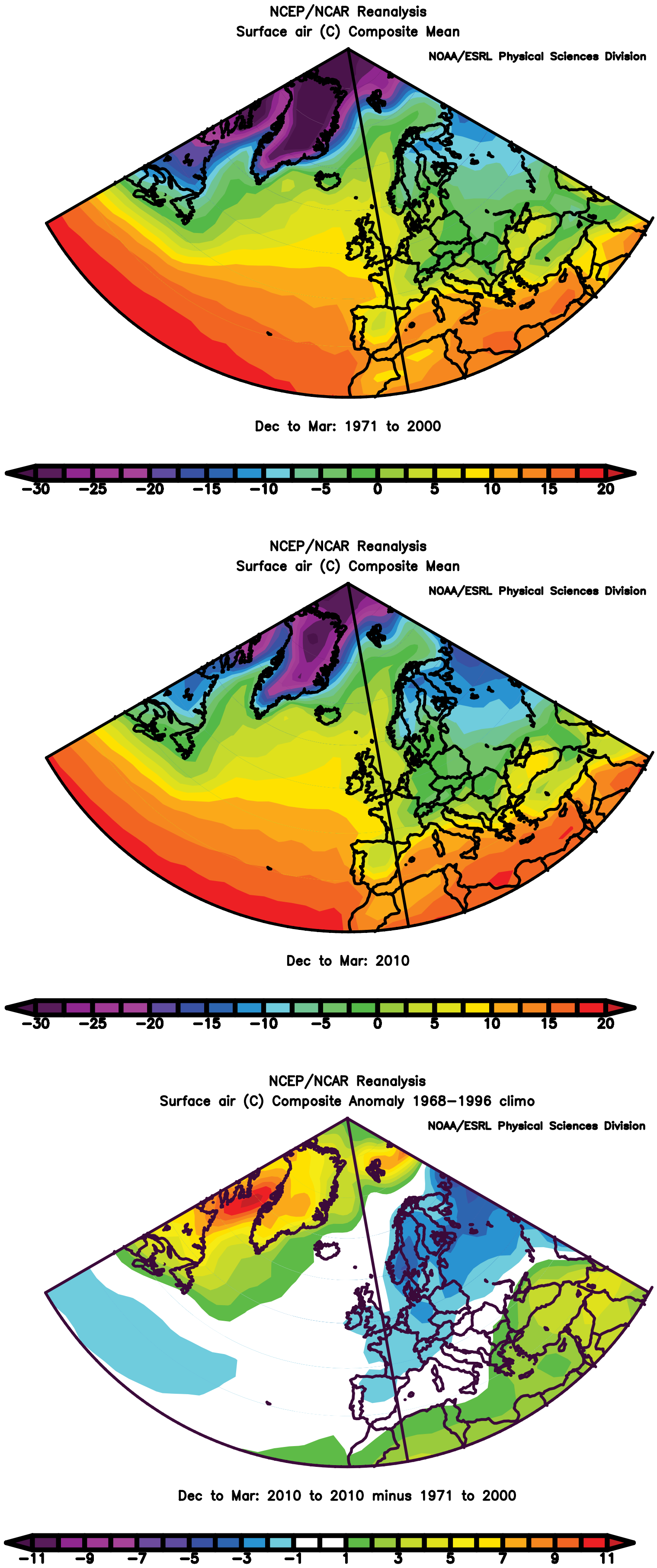


Figure 12.
Winter (DJFM) surface air temperature fields. Top panel: surface air temperature averaged over 30 years (1971–2000). Middle panel: temperatures in winter 2010 (December 2009, January to March 2010). Bottom panel: winter 2010 surface air temperature anomaly – the difference between the top and middle panels. Images provided by the NOAA/ESRL Physical Sciences Division, Boulder, CO (available online at http://www.cdc.noaa.gov/).

4. DETAILED AREA DESCRIPTIONS, PART I: THE UPPER OCEAN

4.1 Introduction

In this section, we present time-series from many sustained observations in each of the ICES Areas. The general pattern of oceanic circulation in the upper layers of the North Atlantic, in relation to the areas described here, is given in Figure 13. In addition to temperature and salinity, we present other indices where they are available, such as air-temperature and sea-ice indices. The text summarizes the regional context of the sections and stations, noting any significant recent events.

Most standard sections or stations are sampled annually or more frequently. Often, the time-series presented here have been extracted from larger datasets and chosen as indicators of the conditions in a particular area. Where appropriate, data are presented as anomalies to demonstrate how the values compare with the average, or "normal", conditions (usually the long-term mean of each parameter during 1971–2000). For datasets that do not extend as far back as 1971, the average conditions have been calculated from the start of the dataset up to 2000.

In places, the seasonal cycle has been removed from a dataset, either by calculating the average seasonal cycle during 1971–2000 or by drawing on other sources, such as regional climatology datasets. Smoothed versions of most time-series are included using a "loess smoother", a locally weighted regression with a two- or five-year window.

In some areas, data are sampled regularly enough to allow a good description of the seasonal cycle. Where possible, monthly data from 2010 are presented and compared with the average seasonal conditions and statistics.

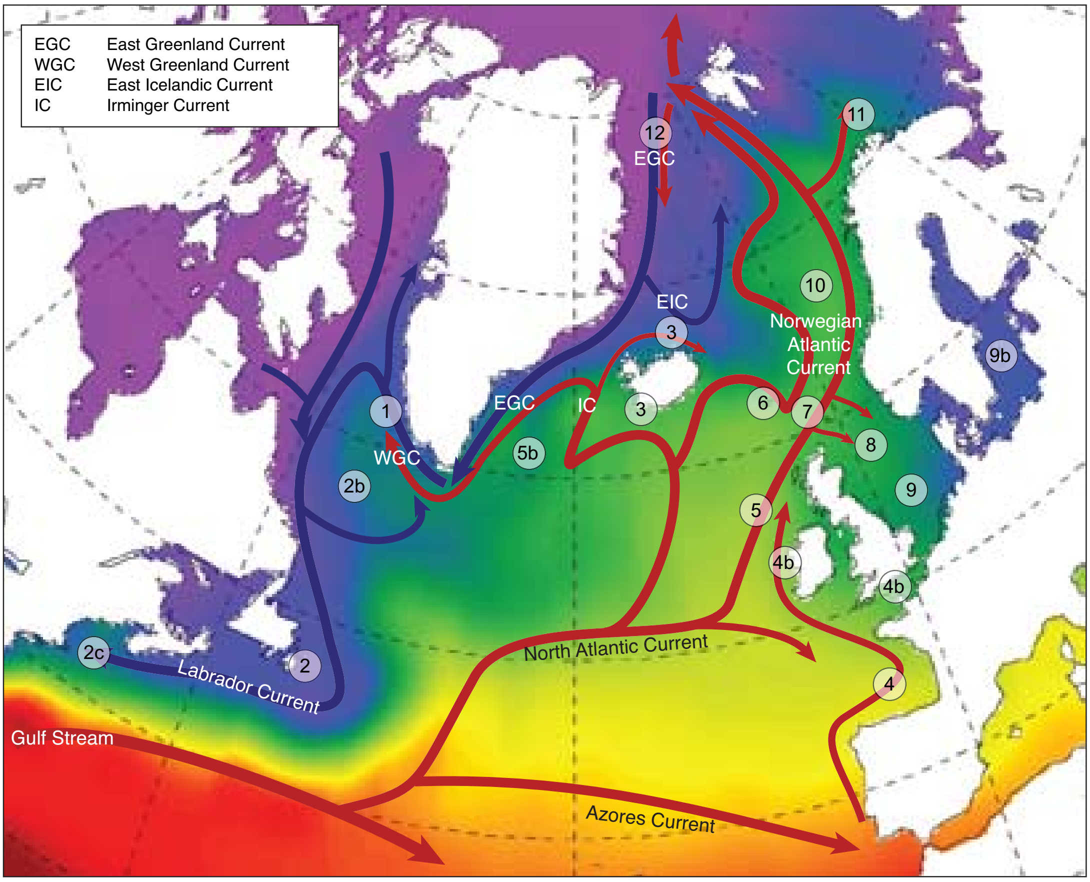


Figure 13.
Schematic of the general circulation of the upper ocean (0–1000 m) in the North Atlantic in relation to the numbered areas presented below. Blue arrows = movement of cooler waters of the Subpolar Gyre; red arrows = movement of warmer waters of the Subtropical Gyre.

4.2 Area 1 – West Greenland

THE WEST GREENLAND CURRENT CARRIES WATER NORTH ALONG THE WEST COAST OF GREENLAND AND CONSISTS OF TWO COMPONENTS: A COLD AND FRESH INSHORE COMPONENT, WHICH IS A MIXTURE OF POLAR WATER AND MELTWATER, AND THE MORE SALINE AND WARMER IRMINGER SEAWATER. THE WEST GREENLAND CURRENT IS A PART OF THE CYCLONIC SUBPOLAR GYRE AND IS SUBJECT TO HYDROGRAPHIC VARIATIONS AT DIFFERENT TIME-SCALES. THE HYDROGRAPHIC CONDITIONS ARE REGULARLY MONITORED AT TWO OCEANOGRAPHIC SECTIONS ACROSS THE CONTINENTAL SLOPE OF WEST GREENLAND. TWO OFFSHORE STATIONS AT EACH SECTION DOCUMENT CHANGES IN HYDROGRAPHIC CONDITIONS OFF WEST GREENLAND.

West Greenland lies within an area that normally experiences warmer conditions when the NAO index is negative. In 2010, western and eastern Greenland experienced extreme warm atmospheric conditions. The mean air temperature at Nuuk station was 2.6°C in 2010 and reached its highest value in the whole series of observations since 1876. This was consistent with the strongly negative NAO index in winter 2009/2010.

The water properties between 0 and 50 m depth at Fyllas Bank Station 4 are used to monitor the variability of the fresh Polar Water component of the West Greenland Current (WGC). In 2010, the temperature of this water was 1.2°C higher than the long-term mean (1983–2000), owing to the heat flux from the warm atmosphere. The salinity anomaly of the Polar Water was also positive, but rather small (0.13).

The temperature, salinity, and volume of the Irminger Sea Water component of the WGC started to increase at the end of the 1990s, coinciding with the slowing of the Subpolar Gyre. In 2010, the water temperature in the 75–200 m layer at Cape Desolation Station 3 was 6.4°C, which was the fifth highest temperature since 1983. In contrast, the salinity anomaly (0.02) was smaller than previous years.

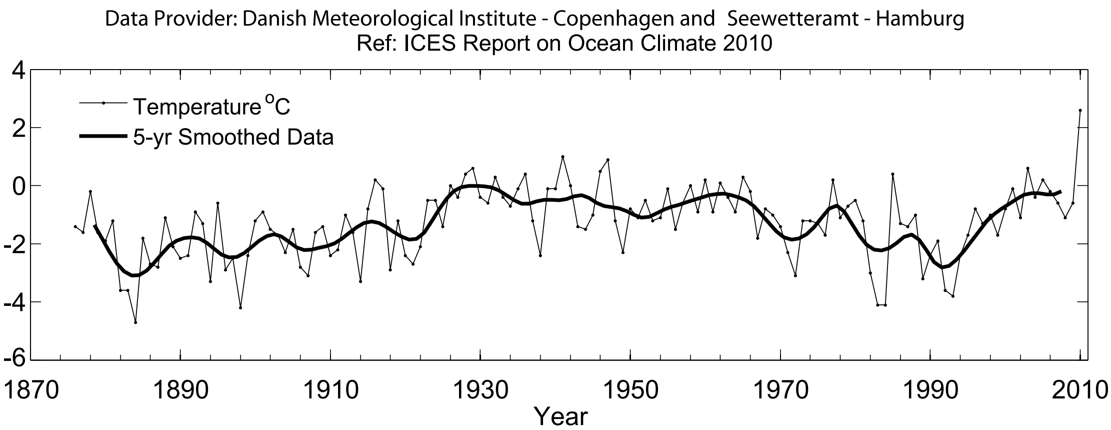


Figure 14.
Area 1 – West Greenland. Annual mean air temperature at Nuuk weather station (64.16°N 51.75°W).

POLAR WATER WEST OF GREENLAND WAS 1.2°C ABOVE AVERAGE IN 2010.

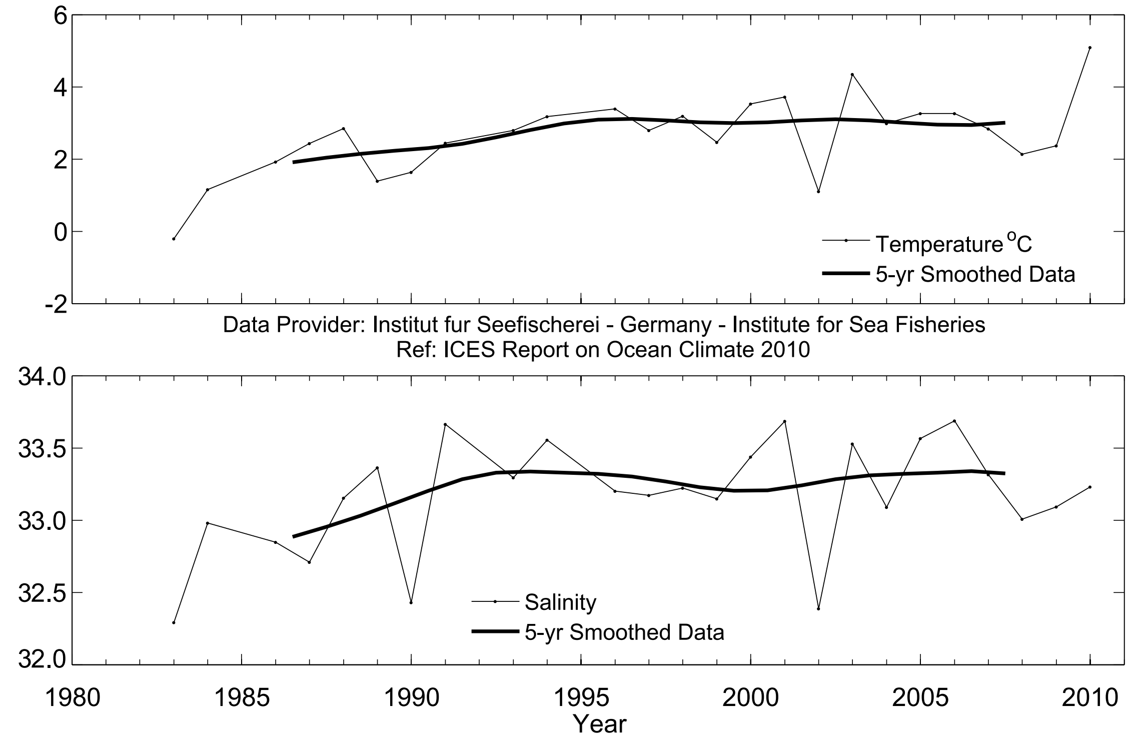


Figure 15.
Area 1 – West Greenland. Mean temperature (upper panel) and salinity (lower panel) in the 0–50 m water layer at Fyllas Bank Station 4 (63.88°N 53.37°W).

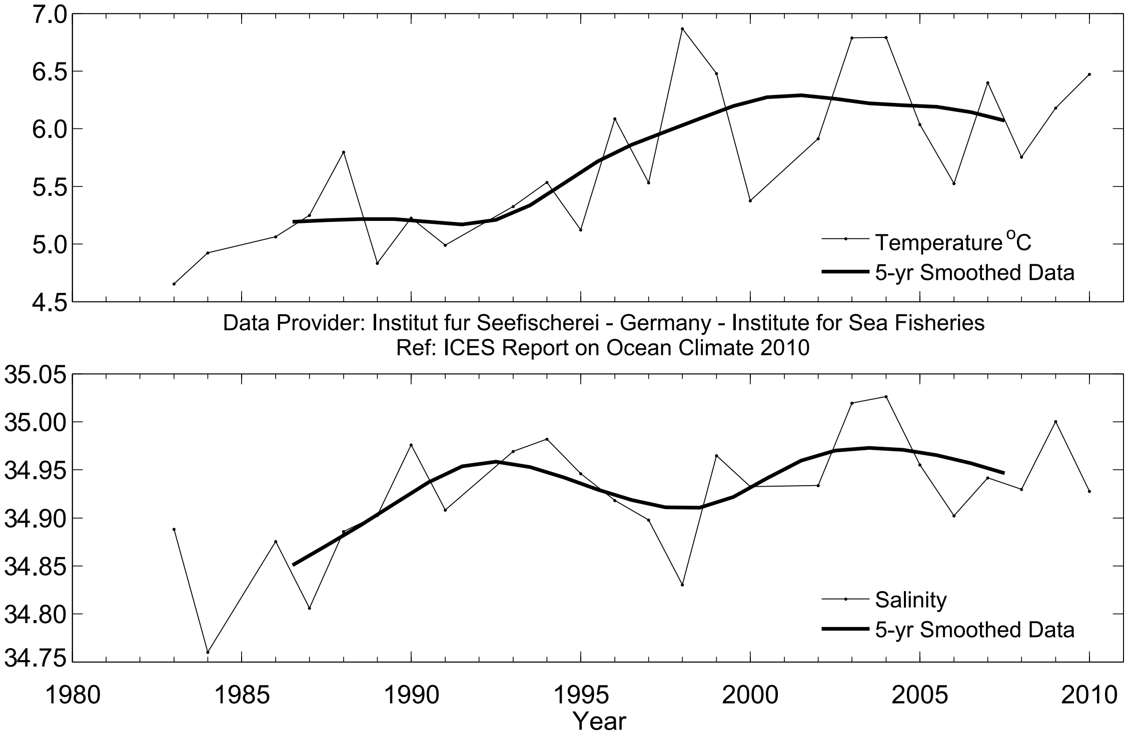


Figure 16.
Area 1 – West Greenland. Temperature (upper panel) and salinity (lower panel) at 75–200 m at Cape Desolation Station 3 (60.45°N 50°W).

4.3 Area 2 – Northwest Atlantic: Scotian Shelf and the Newfoundland–Labrador Shelf

Scotian Shelf

THE CONTINENTAL SHELF OFF THE COAST OF NOVA SCOTIA IS CHARACTERIZED BY COMPLEX TOPOGRAPHY CONSISTING OF MANY OFFSHORE SHALLOW BANKS AND DEEP MID-SHELF BASINS. IT IS SEPARATED FROM THE SOUTHERN NEWFOUNDLAND SHELF BY THE LAURENTIAN CHANNEL AND BORDERS THE GULF OF MAINE TO THE SOUTHWEST. SURFACE CIRCULATION IS DOMINATED BY A GENERAL FLOW TOWARDS THE SOUTHWEST, INTERRUPTED BY CLOCKWISE MOVEMENT AROUND THE BANKS AND ANTICLOCKWISE MOVEMENT AROUND THE BASINS, WITH THE STRENGTHS VARYING SEASONALLY.

HYDROGRAPHIC CONDITIONS ON THE SCOTIAN SHELF ARE DETERMINED BY HEAT TRANSFER BETWEEN THE OCEAN AND ATMOSPHERE, INFLOW FROM THE GULF OF ST LAWRENCE AND THE NEWFOUNDLAND SHELF, AND EXCHANGE WITH OFFSHORE SLOPE WATERS. WATER PROPERTIES HAVE LARGE SEASONAL CYCLES AND ARE MODIFIED BY FRESHWATER RUN-OFF, PRECIPITATION, AND MELTING OF SEA ICE. TEMPERATURE AND SALINITY EXHIBIT STRONG HORIZONTAL AND VERTICAL GRADIENTS THAT ARE MODIFIED BY DIFFUSION, MIXING, CURRENTS, AND SHELF TOPOGRAPHY.

In 2010, annual mean air temperatures over the Scotian Shelf, represented by Sable Island observations, were 1.1°C, corresponding to 1.7 standard deviations (s.d.) above the long-term mean (based on 1981–2010 mean and s.d. values). The amount of sea ice on the Scotian Shelf in 2010, as measured by the total area of ice seaward of Cabot Strait between Nova Scotia and Newfoundland from January to April, was 160 km^2, well below the long-term mean coverage of 39 000 km^2. This is the second lowest coverage in the 42-year time-series; only 1969, with an ice cover of 10 km^2, had less ice.

Topography separates the northeastern Scotian Shelf from the rest of the shelf. In the northeast, the bottom tends to be covered by relatively cold waters (1–4°C), whereas the basins in the central and southwestern regions typically have bottom temperatures of 8–10°C. The origin of the latter is the offshore slope waters, whereas in the northeast, the water comes principally from the Gulf of St Lawrence. The interannual variability of the two water masses differs.

Measurements of temperatures at 100 m at the Misaine Bank station capture the changes in the northeast. They revealed average conditions in 2010, with temperature above normal (by 0.43°C, +0.7 s.d.) and salinity slightly above normal (by 0.04, +0.3 s.d.).

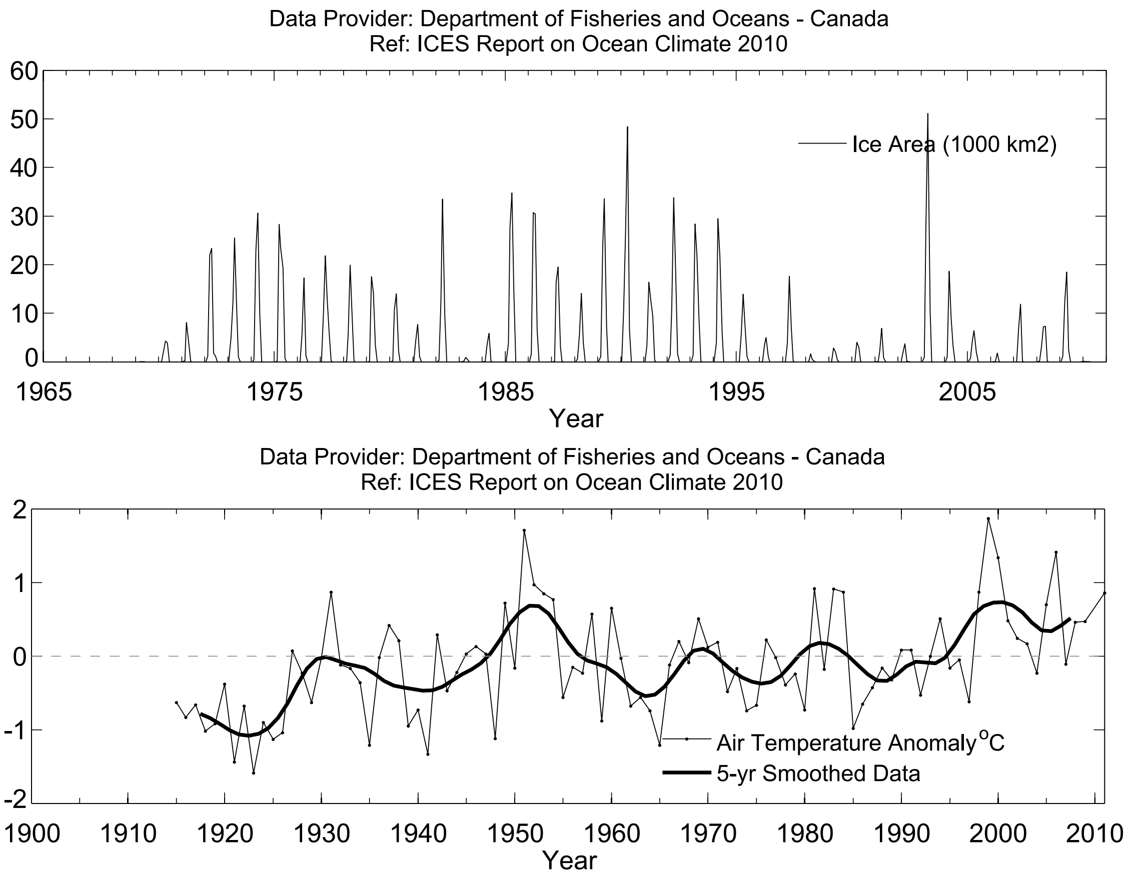


Figure 17.
Area 2 – Northwest Atlantic: Scotian Shelf. Monthly means of ice area seawards of Cabot Strait (upper panel) and air temperature at Sable Island on the Scotian Shelf (lower panel).

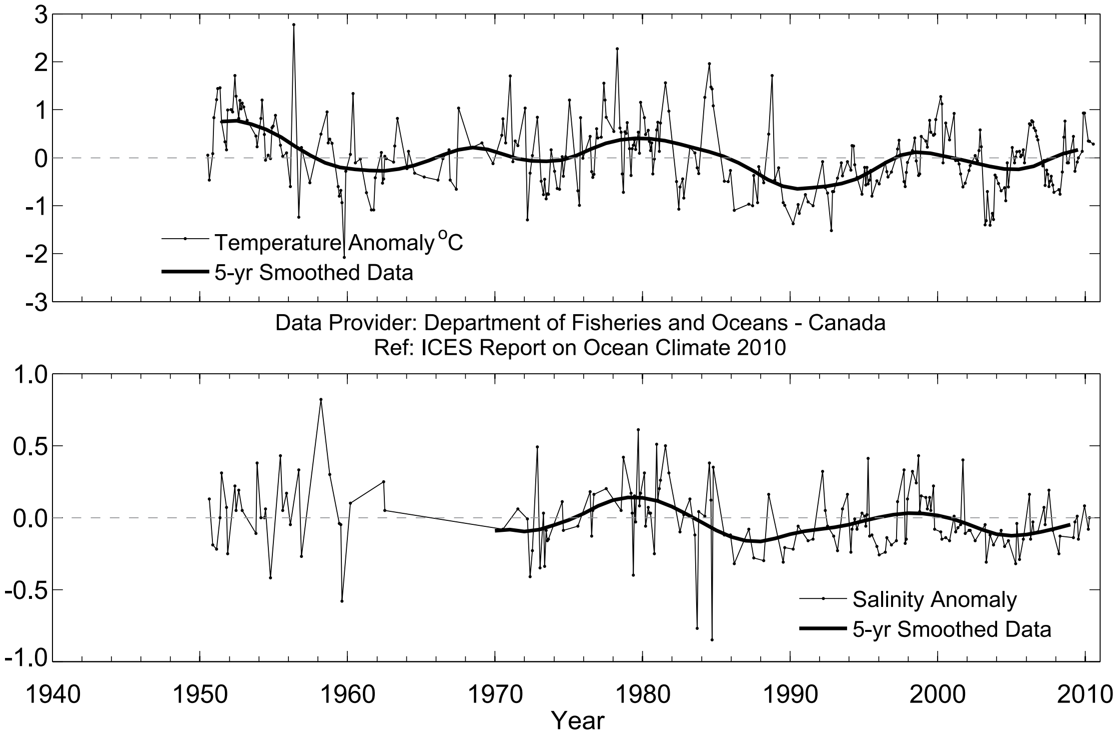


Figure 18.
Area 2 – Northwest Atlantic: Scotian Shelf. Near-bottom temperature anomalies (upper panel) and salinity anomalies (lower panel) at Misaine Bank (100 m).

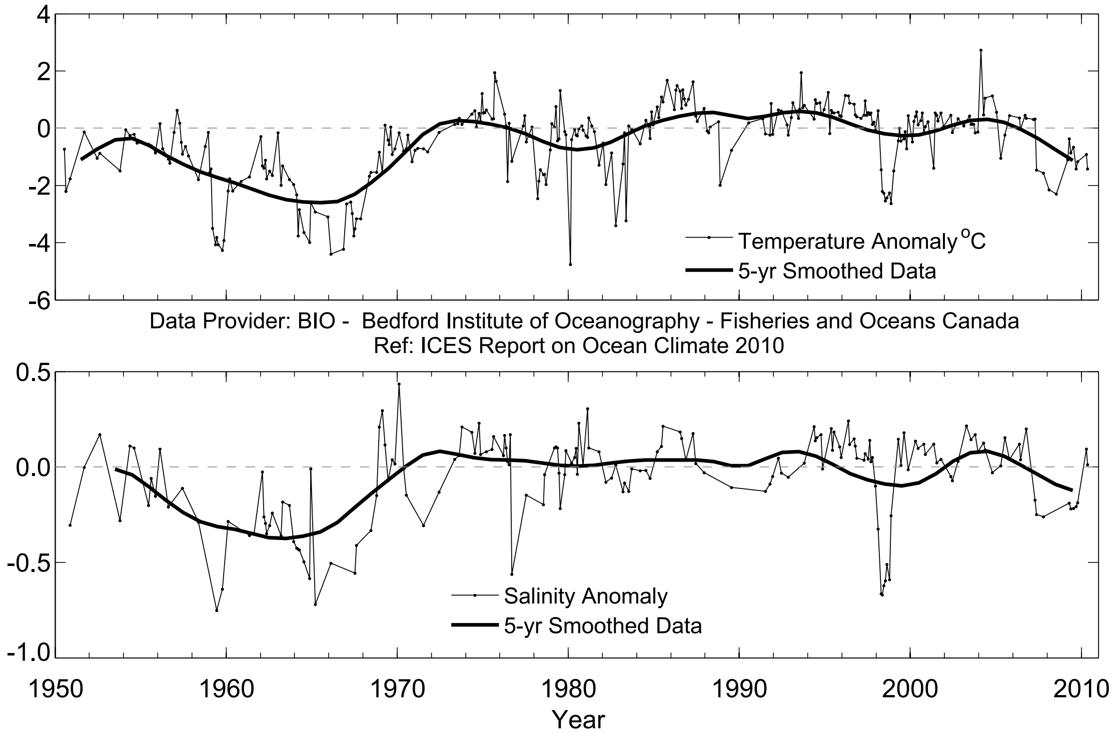


Figure 19.
Area 2 – Northwest Atlantic: Scotian Shelf. Near-bottom temperature anomalies (upper panel) and salinity anomalies (lower panel) in the central Scotian Shelf (Emerald Basin, 250 m).

Newfoundland–Labrador Shelf

THIS REGION IS SITUATED ON THE WESTERN SIDE OF THE LABRADOR SEA, STRETCHING FROM HUDSON STRAIT TO THE SOUTHERN GRAND BANK AND DOMINATED BY SHALLOW BANKS, CROSS-SHELF CHANNELS OR SADDLES, AND DEEP MARGINAL TROUGHS NEAR THE COAST. CIRCULATION IS DOMINATED BY THE SOUTH-FLOWING LABRADOR CURRENT BRINGING COLD, FRESH WATERS FROM THE NORTH, TOGETHER WITH SEA ICE AND ICEBERGS, TO SOUTHERN AREAS OF THE GRAND BANKS.

HYDROGRAPHIC CONDITIONS ARE DETERMINED BY THE STRENGTH OF THE WINTER ATMOSPHERIC CIRCULATION OVER THE NORTHWEST ATLANTIC (NAO), ADVECTION BY THE LABRADOR CURRENT, CROSS-SHELF EXCHANGE WITH WARMER CONTINENTAL SLOPE WATER, AND BOTTOM TOPOGRAPHY. SUPERIMPOSED ARE LARGE SEASONAL AND INTERANNUAL VARIATIONS IN SOLAR HEAT INPUT, SEA-ICE COVER, AND STORM-FORCED MIXING. THE RESULTING WATER MASS ON THE SHELF EXHIBITS LARGE ANNUAL CYCLES WITH STRONG HORIZONTAL AND VERTICAL TEMPERATURE AND SALINITY GRADIENTS.

The NAO index (Iceland–Azores), a key indicator of climate conditions in the Northwest Atlantic, was at a record low in 2010 and, as a result, Arctic air outflow to the Northwest Atlantic was much weaker than normal. This resulted in a broad-scale warming throughout the Northwest Atlantic, from West Greenland to Baffin Island and thence to Labrador and Newfoundland.

Air temperatures were above normal by 2–3 standard deviations (s.d.) and were at a record high at some northern sites on Baffin Island and the Labrador coast. For example, at Cartwright on the Labrador coast, they were 3.3ºC above normal, a significant increase over 2009 values. Sea-ice extent and duration on the Newfoundland–Labrador Shelf decreased in 2010 for the 16th consecutive year, with the January–June average reaching a record low. As a result of these and other factors, local water temperatures on the Newfoundland–Labrador Shelf warmed compared with 2009 and were significantly above normal in most areas.

At the standard monitoring site off eastern Newfoundland (Station 27), the depth-averaged annual water temperature increased to 2 s.d. above normal, the second highest on record after 2006. Annual surface temperatures were also above normal by 1 s.d., whereas bottom values were above normal by 1.7 s.d. Upper-layer salinities at Station 27 decreased to slightly fresher than normal after several years of above-normal values.

A robust index of ocean climate conditions in eastern Canadian waters is the extent of the cold intermediate layer (CIL) of <0°C water overlying the continental shelf. This winter-cooled water remains isolated between the seasonally heated upper layer and the warmer shelf-slope water throughout summer and autumn. During the 1960s, when the NAO was well below normal and had the lowest value ever in the 20th century, the volume of CIL water was at a minimum, and during the high NAO years of the early 1990s, the CIL volume reached near-record-high values. The area of the CIL water mass with temperatures <0°C during 2010 was below normal by 0.6 s.d. off eastern Newfoundland and 1 s.d. off southern Labrador. Average temperature conditions along standard sections in these regions were above normal, whereas salinities were generally below normal.

In summary, ocean temperatures on the Newfoundland–Labrador Shelf experienced a slight cooling trend in 2007–2009 compared with the record highs of 2006, but increased again in 2010 to near-record highs. A composite climate index, derived from several meteorological, sea-ice, and oceanographic temperature and salinity time-series after 2006, was the second highest in 61 years of observations.

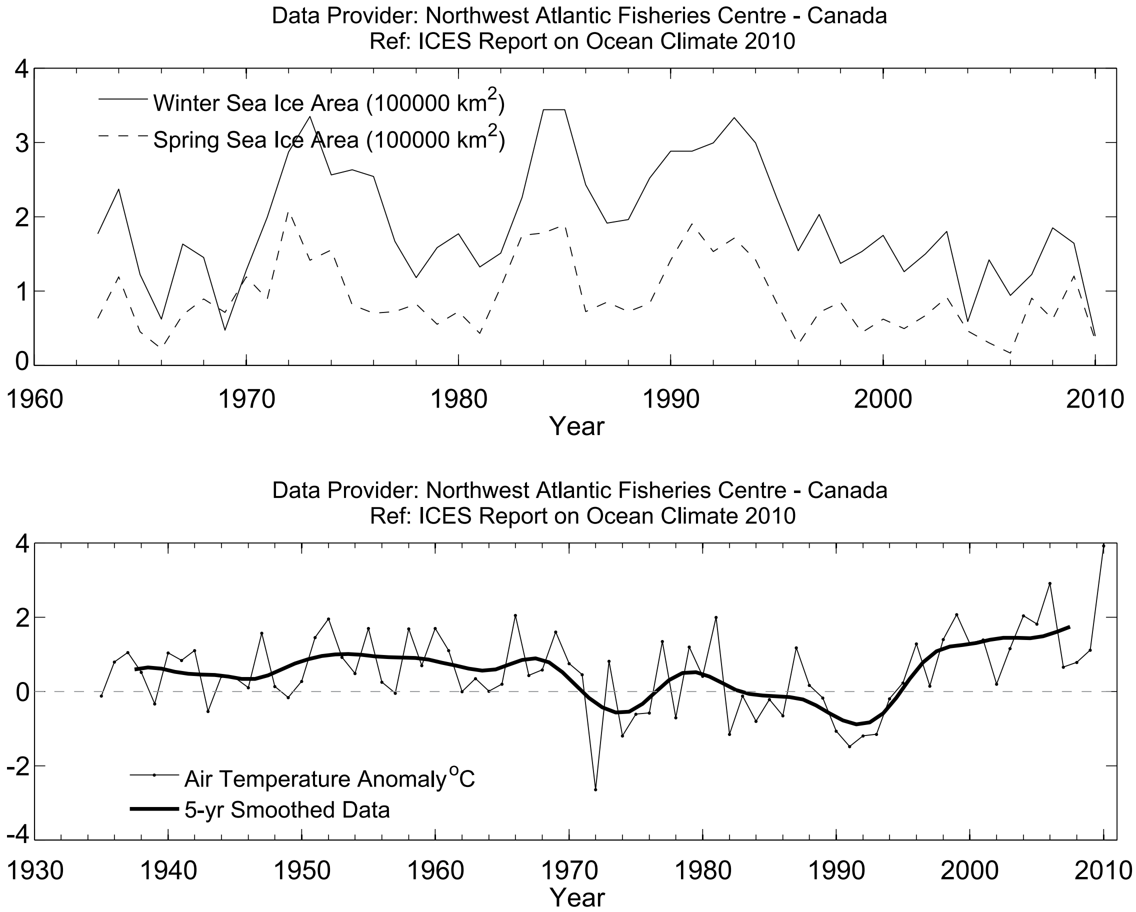
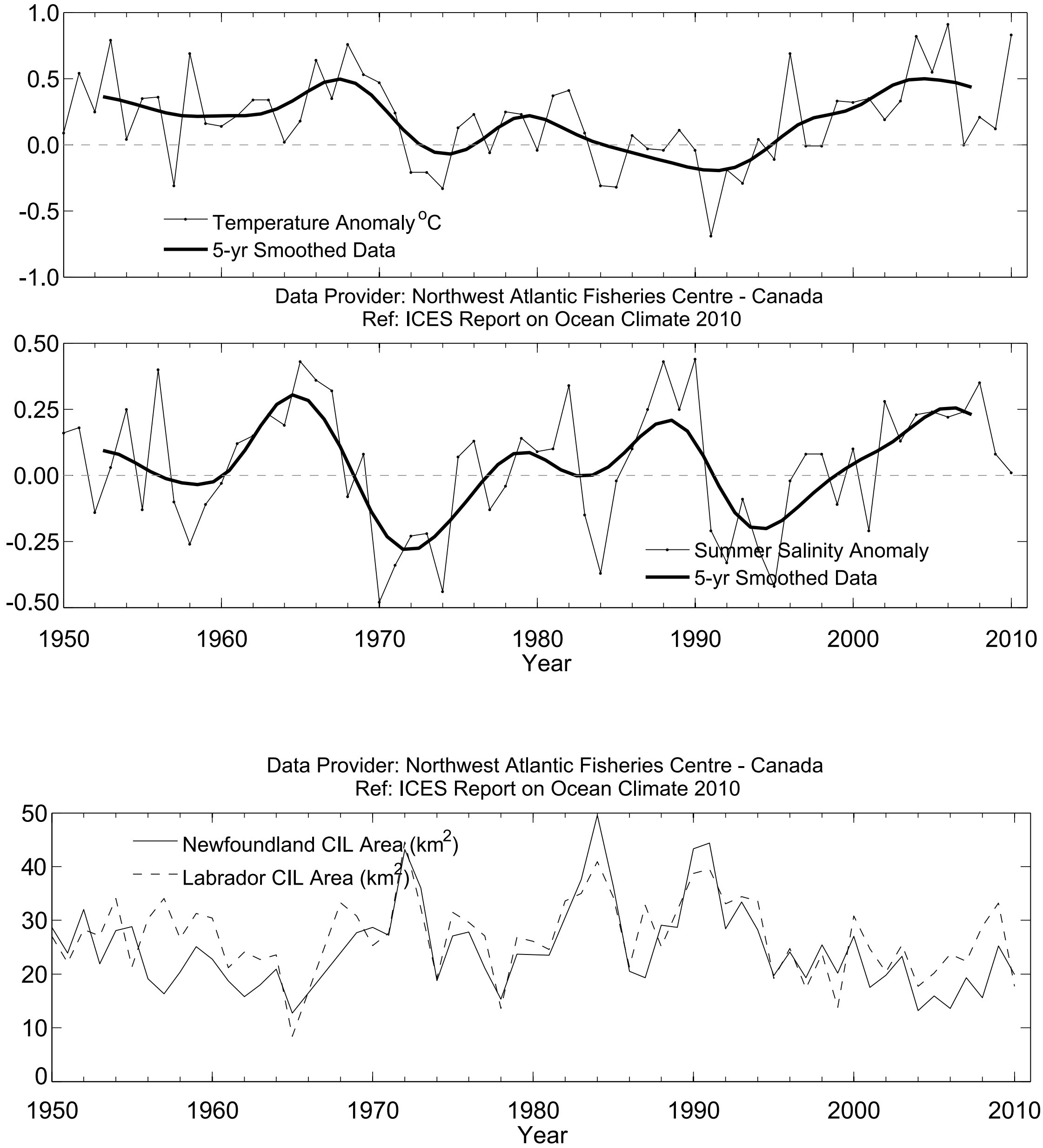


Figure 20.
Area 2 – Northwest Atlantic: Newfoundland–Labrador Shelf. Monthly sea-ice areas off Newfoundland–Labrador between 45° and 55°N (upper panel). Annual air temperature anomalies at Cartwright on the Labrador Coast (lower panel).

HIGH AIR AND WATER TEMPERATURES LED TO VERY LOW SEA-ICE EXTENT AND DURATION.

Figure 21.
Area 2 – Northwest Atlantic: Newfoundland–Labrador Shelf. Annual depth-averaged Newfoundland Shelf temperature anomalies (top panel), salinity anomalies (middle panel), and spatial extent of cold intermediate layer (CIL; bottom panel).



4.4 Area 2b – Labrador Sea

THE LABRADOR SEA IS LOCATED BETWEEN GREENLAND AND THE LABRADOR COAST OF EASTERN CANADA. COLD, LOW-SALINITY WATERS OF POLAR ORIGIN CIRCLE THE LABRADOR SEA IN AN ANTICLOCKWISE CURRENT SYSTEM THAT INCLUDES BOTH THE NORTH-FLOWING WEST GREENLAND CURRENT ON THE EASTERN SIDE AND THE SOUTH-FLOWING LABRADOR CURRENT ON THE WESTERN SIDE. WARM AND SALINE ATLANTIC WATERS ORIGINATING IN THE SUBTROPICS FLOW NORTH INTO THE LABRADOR SEA ON THE GREENLAND SIDE AND BECOME COLDER AND FRESHER AS THEY CIRCULATE.

CHANGES IN LABRADOR SEA HYDROGRAPHIC CONDITIONS ON INTERANNUAL TIME-SCALES DEPEND ON THE VARIABLE INFLUENCES OF HEAT LOSS TO THE ATMOSPHERE, HEAT AND SALT GAIN FROM ATLANTIC WATERS, AND FRESHWATER GAIN FROM ARCTIC OUTFLOW, MELTING SEA ICE, PRECIPITATION, AND RUN-OFF. A SEQUENCE OF SEVERE WINTERS IN THE EARLY 1990S LED TO DEEP CONVECTION, PEAKING IN 1993–1994, THAT FILLED THE UPPER 2 KM OF THE WATER COLUMN WITH COLD, FRESH WATER. CONDITIONS HAVE GENERALLY BEEN MILDER SINCE THE MID-1990S. THE UPPER LEVELS OF THE LABRADOR SEA HAVE BECOME WARMER AND MORE SALINE AS HEAT LOSSES TO THE ATMOSPHERE HAVE DECREASED AND ATLANTIC WATERS HAVE BECOME INCREASINGLY DOMINANT.

The upper 150 m of the west-central Labrador Sea warmed by more than 1°C over the past 15 years, but demonstrated no significant trend in salinity. However, on shorter time-scales, salinity of the same layer increased during 1994–2005 by about 0.3 and decreased over the following years by more than 0.1. Temperature decreased between 2004 and 2009 and started to increase in summer 2009, reaching a record high in 2010. Air temperatures in spring and summer 2010 were the coldest since the early 2000s, and the upper layer of the sea cooled by 0.6°C compared with 2008 conditions.

This is consistent with the noted much higher positive anomaly (5–10°C) in surface air temperatures in the central and southern Labrador Sea during this period, which jointly resulted in reduced heat fluxes from the ocean to the atmosphere.

Labrador Sea sea surface temperatures (SSTs) during JFM 2010 indicate that, in ice-free areas, the winter SST was 1–2°C above normal (averaging period is 1971–2000). The annual mean anomalies for 2010 were similar in pattern and magnitude to those observed during winter. The peak SST anomalies for 2010 occurred in the Labrador Sea during summer, when they reached values greater than 3°C. These results are similar to observations in 2009, when the winter SST was 0.5–1.5°C above normal in the central Labrador Sea.

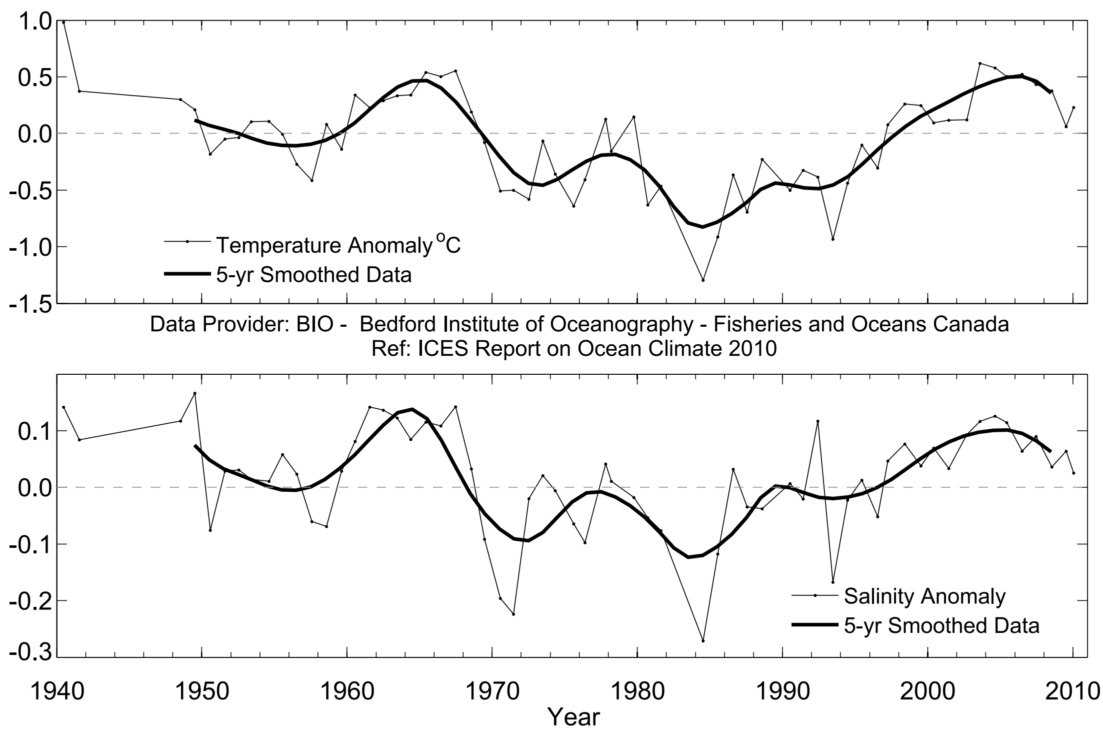


Figure 22.
Area 2b - Labrador Sea. Potential temperature anomaly (upper panel) and salinity anomaly (lower panel) at 0–150 m, from CTD and Argo data in the west-central Labrador Sea (centred at 56.7°N 52.5°W). Estimates of seasonal cycle (derived from all data in the time-series) have been removed from the observations.

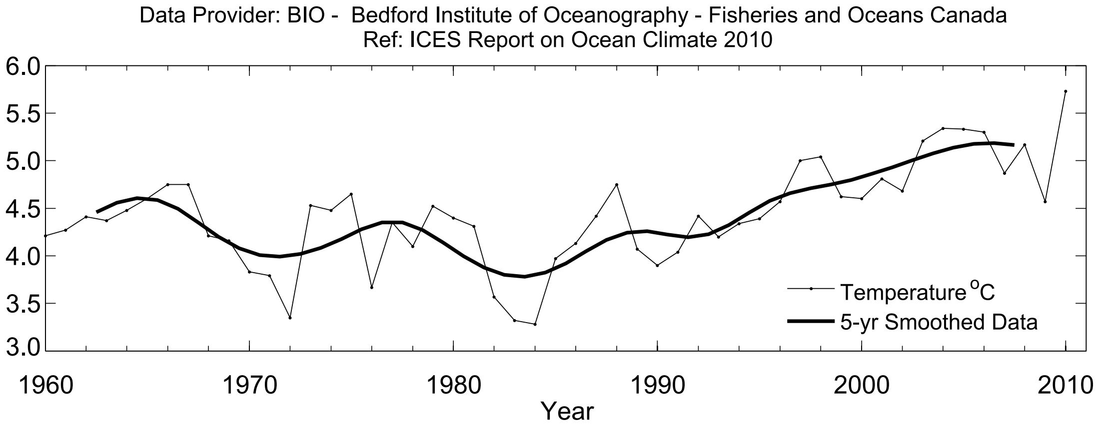


Figure 23.
Area 2b – Labrador Sea. Annual mean sea surface temperature data from the west-central Labrador Sea (56.5°N 52.5°W). Data obtained from the HadISST1.1 sea ice and sea surface temperature dataset, UK Meteorological Office, Hadley Centre.

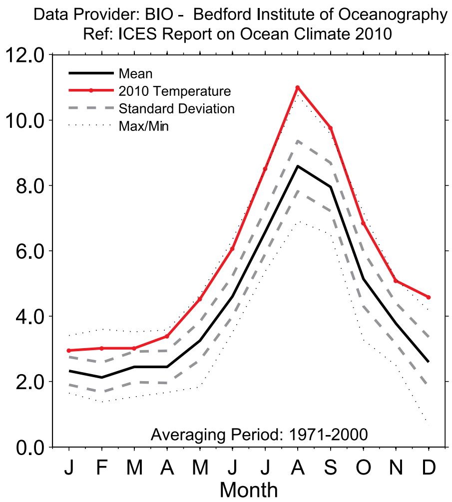


Figure 24.
Area 2b – Labrador Sea. 2010 monthly sea surface temperature data from the west-central Labrador Sea (56.5°N 52.5°W). Data obtained from the HadISST1.1 sea ice and sea surface temperature dataset, UK Meteorological Office, Hadley Centre.

4.5 Area 2c – Mid-Atlantic Bight

HYDROGRAPHIC CONDITIONS IN THE WESTERN NORTH ATLANTIC SLOPE SEA, THE MID-ATLANTIC BIGHT, AND THE GULF OF MAINE DEPEND ON THE SUPPLY OF WATERS FROM THE LABRADOR SEA ALONG BOTH THE SHELF AND THE CONTINENTAL SLOPE. THESE WATERS HAVE BEEN MONITORED BY REGULAR EXPENDABLE BATHYTHERMOGRAPH (XBT) AND SURFACE SALINITY OBSERVATIONS FROM COMMERCIAL AND FISHING VESSELS SINCE 1978. ONE REGULARLY OCCUPIED SECTION EXTENDS FROM AMBROSE LIGHT OFF NEW YORK CITY TOWARDS BERMUDA FOR A DISTANCE OF APPROXIMATELY 450 KM, CROSSING THE CONTINENTAL SHELF AND SLOPE AND EXTENDING INTO GULF STREAM WATER. THE OTHER SECTION TRAVERSES THE GULF OF MAINE, EXTENDING EAST FROM BOSTON TO CAPE SABLE, NOVA SCOTIA, A DISTANCE OF APPROXIMATELY 450 KM. THIS SECTION CROSSES MASSACHUSETTS BAY, WILKINSON BASIN, LEDGES IN THE CENTRAL GULF OF MAINE, CROWELL BASIN, AND THE WESTERN SCOTIAN SHELF. HYDROGRAPHIC CONDITIONS THROUGHOUT THE SHELF HAVE ALSO BEEN MONITORED ANNUALLY SINCE 1977 AS PART OF THE QUARTERLY ECOSYSTEM MONITORING AND BOTTOM-TRAWL SURVEYS. THE SHELF-WIDE SURVEYS EXTEND FROM CAPE HATTERAS INTO THE GULF OF MAINE, INCLUDING GEORGES BANK AND THE NORTHEAST CHANNEL.

Figure 26 shows surface and bottom temperature anomalies relative to a 30-year mean along the XBT line southeast of New York City. In 2010, warming was observed in the surface waters along the entire section compared with the previous year, with enhanced warming confined to the inner shelf. However, a similar warming trend did not extend to the bottom.

More significant changes were observed in the XBT records along the line crossing the Gulf of Maine, with a marked departure from previous years in both the surface and bottom layers (Figure 27). Here, surface conditions were significantly warmer along the entire section, with the most pronounced warming centred over the western Gulf of Maine (crossing Wilkinson Basin) and weaker warming crossing the deep basins to the east. Bottom conditions demonstrated the opposite trend, with significant cooling in the west and some indication of warming over the deep basins toward the east.

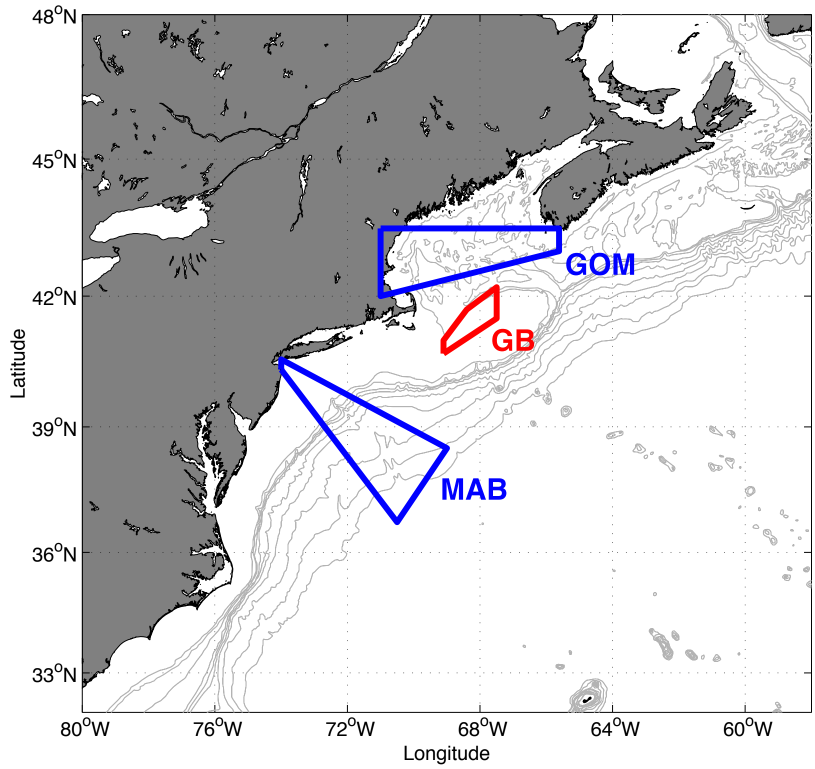


Figure 25.
Area 2c – Mid-Atlantic Bight. The four regions of ongoing time-series: GOM = Gulf of Maine (XBT measurements and surface samples); MAB = central Mid-Atlantic Bight (XBT measurements and surface samples); NEC = Northeast Channel (CTD stations); NWGB = Northwest Georges Bank (CTD stations). The hydrographic station distribution for a typical Northeast Fisheries Science Center (National Marine Fisheries Service, USA) bottom-trawl survey is shown (closed circles). The 50, 100, 500, 1000, 2000, and 3000 m isobaths are also shown.

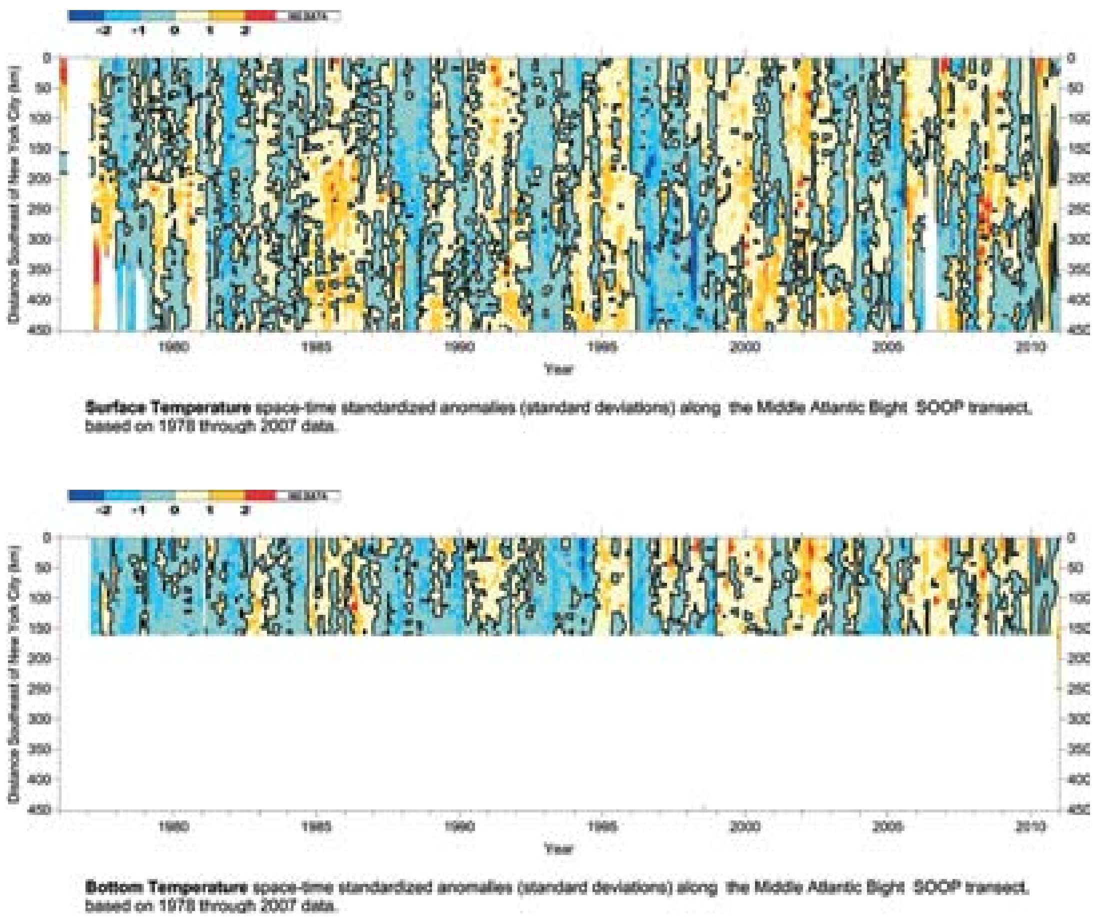


Figure 26.
Area 2c – Mid-Atlantic Bight. Surface and bottom temperatures in the central Mid-Atlantic Bight. Upper panel: surface temperature anomaly (relative to the base period of 1978–2007) from XBT measurements; the origin of the line is New York City. Lower panel: bottom temperature anomaly from XBT measurements. The data are truncated at 160 km to avoid artefacts resulting from incursions of shelf/slope and Gulf Stream fronts. Data provider: National Marine Fisheries Service, USA.

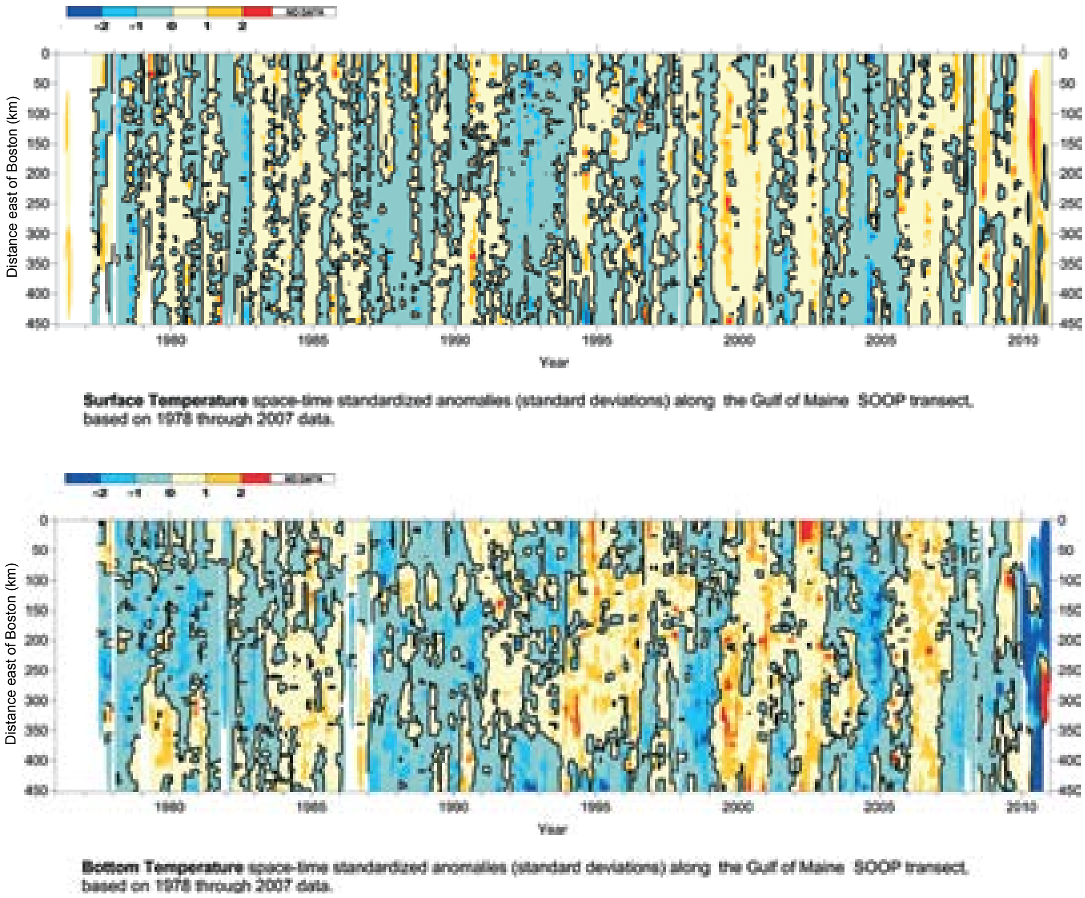


Figure 27.
Area 2c – Mid-Atlantic Bight. Surface and bottom temperatures in the Gulf of Maine. Upper panel: surface temperature anomaly (relative to the base period of 1978–2007) from XBT measurements; the origin of the line is Boston, Massachusetts. Lower panel: bottom temperature anomaly from XBT measurements. Data provider: National Marine Fisheries Service, USA.

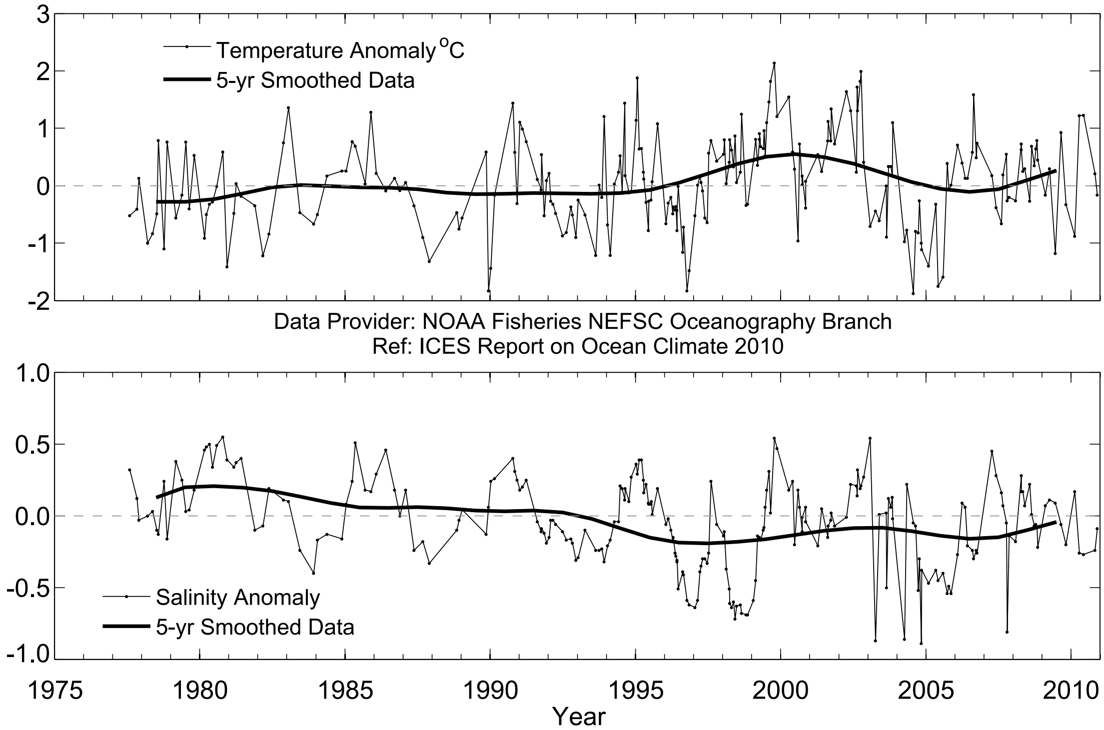


Figure 28.
Area 2c – Mid-Atlantic Bight. Time-series plots of 0–30 m averaged temperature anomaly (upper panel) and salinity anomaly (lower panel) on northwest Georges Bank. Data provider: National Marine Fisheries Service, USA.

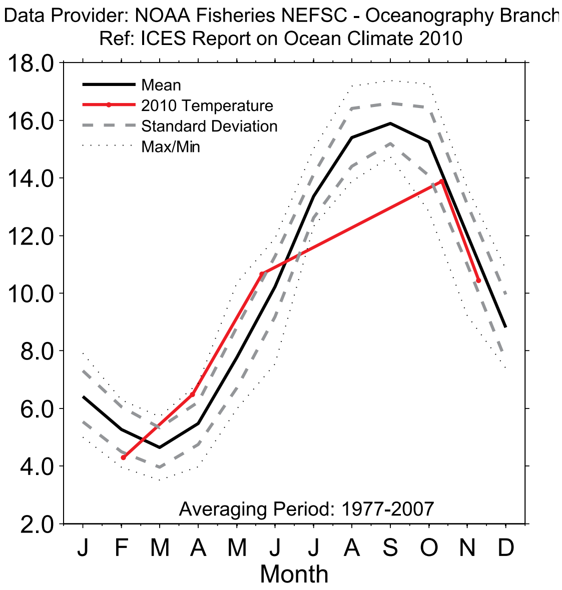


Figure 29.
Area 2c – Mid-Atlantic Bight. 2010 monthly temperatures (0–30 m) at Georges Bank.

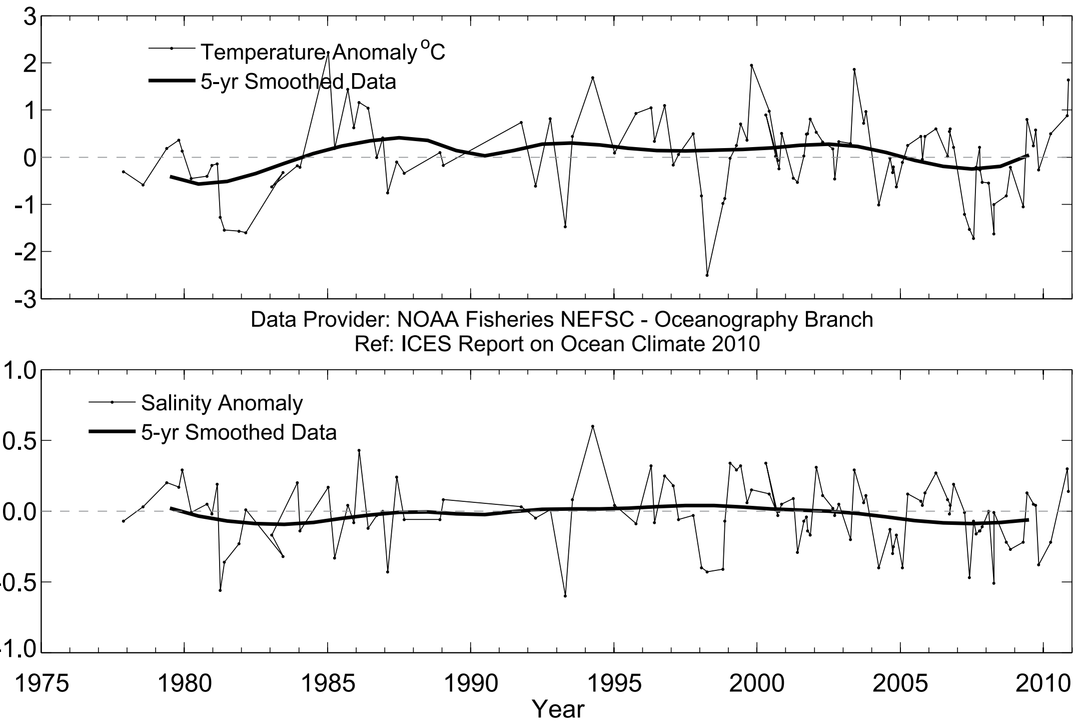


Figure 30.
Area 2c – Mid-Atlantic Bight. Time-series plots of 150–200 m averaged temperature anomaly (upper panel) and salinity anomaly (lower panel) in the Northeast Channel. Data provider: National Marine Fisheries Service, USA.

Voluntary observing ships

- Many of the data presented here are collected from commercial vessels that voluntarily make ocean measurements along their journeys. The results from monthly sampling of surface and bottom temperatures for nearly three decades reveal the power of systematic or repeat sampling from merchant marine vessels. A number of vessels are now operating automated systems to sample temperature and salinity while underway. The key to success with these is to ensure that the data become available as soon as the vessel makes a port call. There is a pressing need for merchant-marine-optimized techniques to track and report data from the ocean in a timely fashion.

The section east of Boston has depended upon observations from various vessels, including those from Eimskipafelag, Caribou Seafoods, the US Coast Guard, and Hans Speck and Son. Their cooperation is greatly appreciated.

4.6 Area 3 – Icelandic Waters

Iceland is at the meeting place of warm and cold currents. These converge in an area of submarine ridges (Greenland–Scotland Ridge, Reykjanes Ridge, Kolbeinsey Ridge) that form natural barriers to the main ocean currents. The warm Irminger Current, a branch of the North Atlantic Current (6–8°C), flows from the south, and the cold East Greenland and East Icelandic currents (-10° to 2°C) flow from the north. Deep bottom currents in the seas around Iceland are principally the overflow of cold water from the Nordic Seas and the Arctic Ocean over the submarine ridges into the North Atlantic.

Hydrographic conditions in Icelandic waters are generally closely related to atmospheric or climatic conditions in and over the country and the surrounding seas, mainly through the Iceland Low-pressure and Greenland High-pressure systems. These conditions in the atmosphere and the surrounding seas affect biological conditions, expressed through the food chain in the waters, including recruitment and abundance of commercially important fish stocks.

In 2010, mean air temperatures in the south (Reykjavik) and north (Akureyri) were above the long-term averages. During the year, temperature and salinity south and west of Iceland remained high, with record-high summer temperatures in upper layers west of Iceland. In the north, summer and autumn temperatures and salinities of surface layers were above average. Salinity and temperature in the East Icelandic Current in spring 2010 were above average.

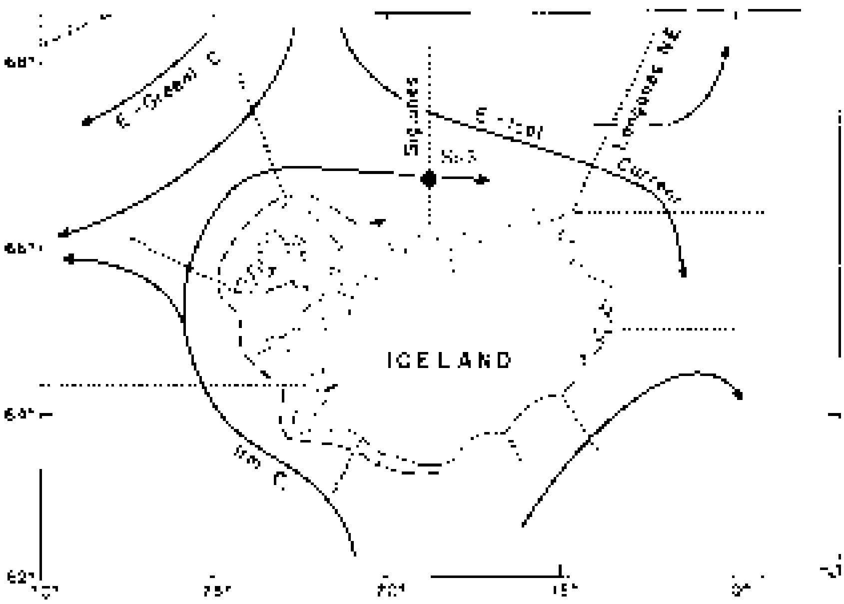


Figure 31.
Area 3 – Icelandic waters. Main currents and location of standard sections in Icelandic waters.

Temperature and salinity around Iceland were above average in 2010.

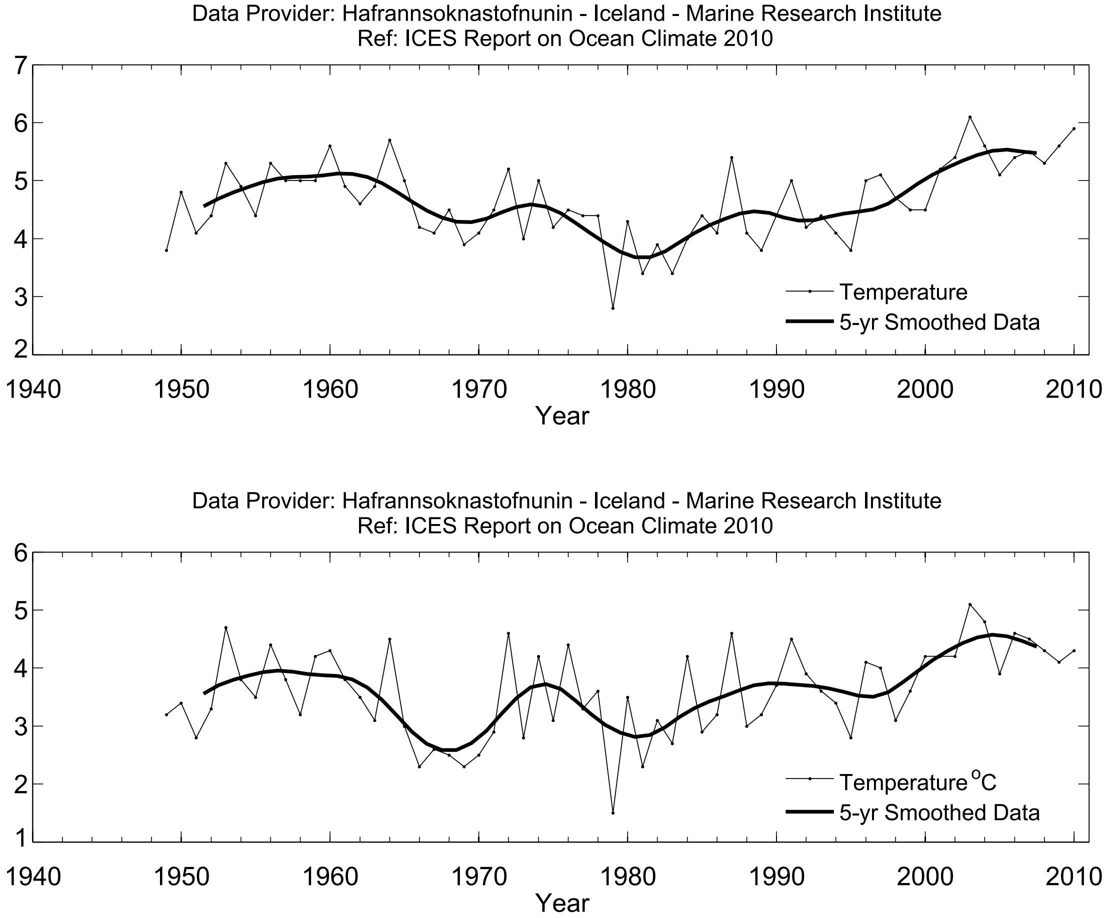


Figure 32.
Area 3 – Icelandic waters. Mean annual air temperature at Reykjavík (upper panel) and Akureyri (lower panel).

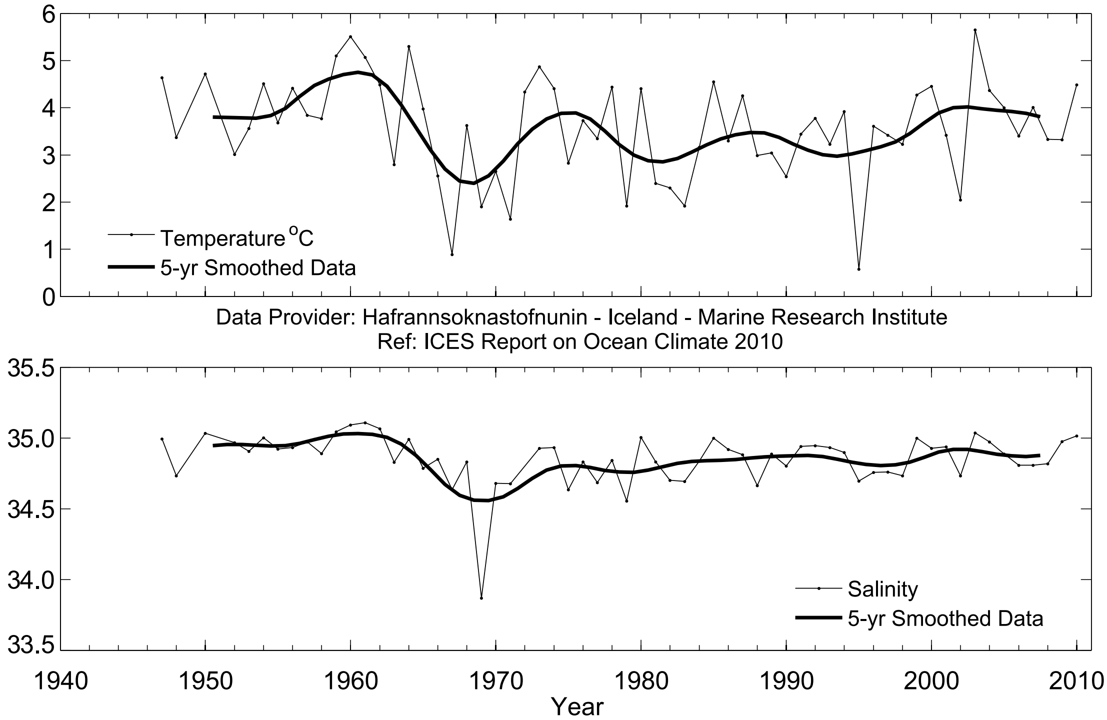


Figure 33.
Area 3 – Icelandic waters. Temperature (upper panel) and salinity (lower panel) at 50–150 m at Siglunes Stations 2–4 in North Icelandic waters.

Figure 34.
Area 3 – Icelandic waters. Temperature (upper panel) and salinity (lower panel) at 0–200 m at Selvogsbanki Station 5 in South Icelandic waters.

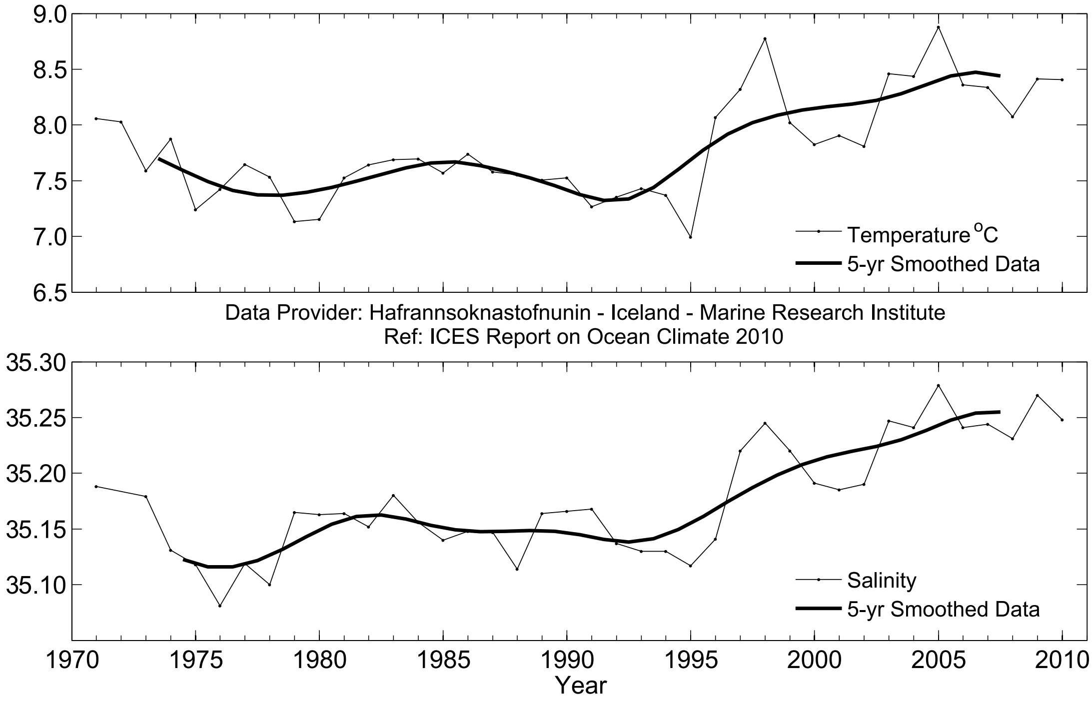
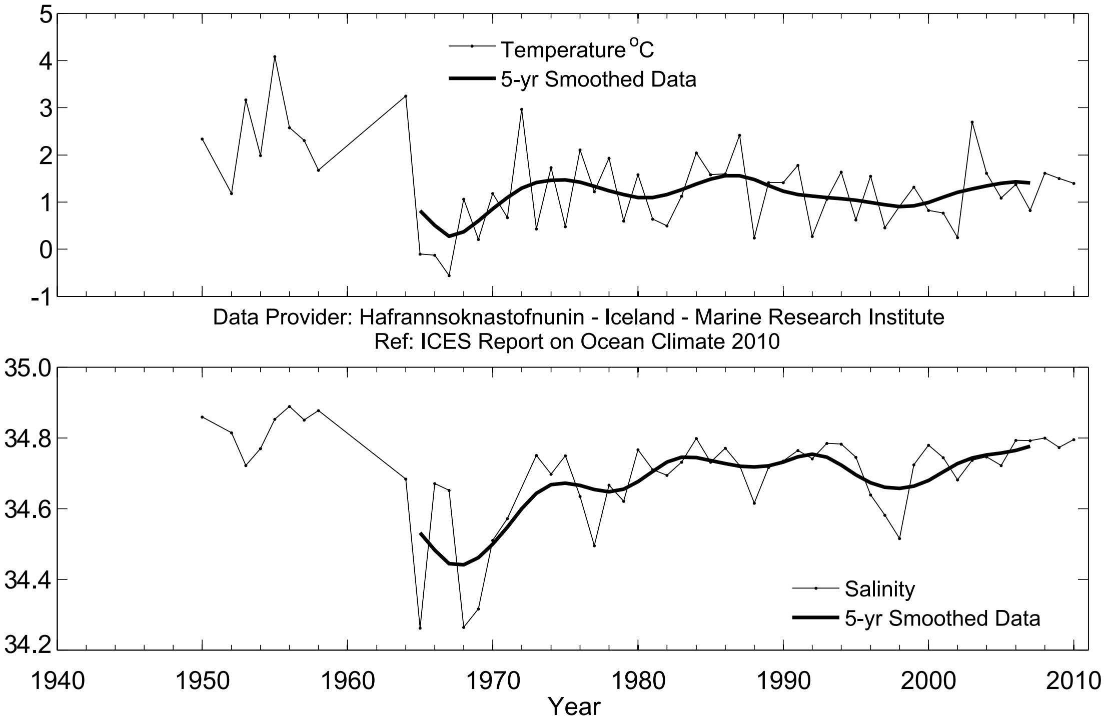


Figure 35.
Area 3 – Icelandic waters. Temperature (upper panel) and salinity (lower panel) at 0–50 m in the East Icelandic Current (Langanes Stations 2–6).



4.7 Area 4 – Bay of Biscay and eastern North Atlantic

THE BAY OF BISCAY IS LOCATED IN THE EASTERN NORTH ATLANTIC. ITS GENERAL CIRCULATION FOLLOWS THE SUBTROPICAL ANTICYCLONIC GYRE AND IS RELATIVELY WEAK. SHELF AND SLOPE CURRENTS ARE IMPORTANT FEATURES HERE, CHARACTERIZED BY COASTAL UPWELLING EVENTS IN SPRING AND SUMMER, AND THE DOMINANCE OF A GEOSTROPHIC BALANCED POLEWARD FLOW (IBERIAN POLEWARD CURRENT) IN AUTUMN AND WINTER.

In 2010, the atmosphere over the Iberian Peninsula was warm with respect to the long-term mean, with the average temperature 0.35ºC above the mean during the reference period (1971–2000). However, it was the coolest year since 1996. In the southern Bay of Biscay, local meteorological stations reported a diverse range of anomalies, ranging from ~0.4ºC to close to zero at the easternmost part (where it was the coldest year of the last two decades). The year was characterized by a cold winter and late autumn, whereas spring and summer were warmer than average.

Surface temperature responded accordingly, yielding the same pattern: cold in winter and slightly warmer in summer (compared with the 1990s and 2000s). Winter cooling allowed deep winter mixed layers, especially towards the southeastern corner. The subsurface structure was conditioned by strong intrusions of southern-origin waters along the slope in winter and late autumn, and a very shallow summer mixed layer caused by persistent summer upwelling conditions. The overall combination of these features resulted in the upper ocean being influenced by the mixed-layer development (0–300 dbar), in a year with very high salinity values and lower-than-average temperatures.

Below the depth of the maximum development of the winter mixed layer, central waters returned to the long-term warming after the cooling and freshening shift that was observed in 2009. At the deeper level of the Mediterranean Water, the properties have remained stable since the mid-2000s.

STRONG ADVECTION PULSES OF SOUTHERN-ORIGIN WATERS COMPENSATED FOR THE FRESHWATER INPUTS, PUSHING SALINITY LEVELS TO THEIR HIGHEST VALUES IN SHELF AND SLOPE WATERS.

Image courtesy of H. Klein, BSH Hamburg, Germany.

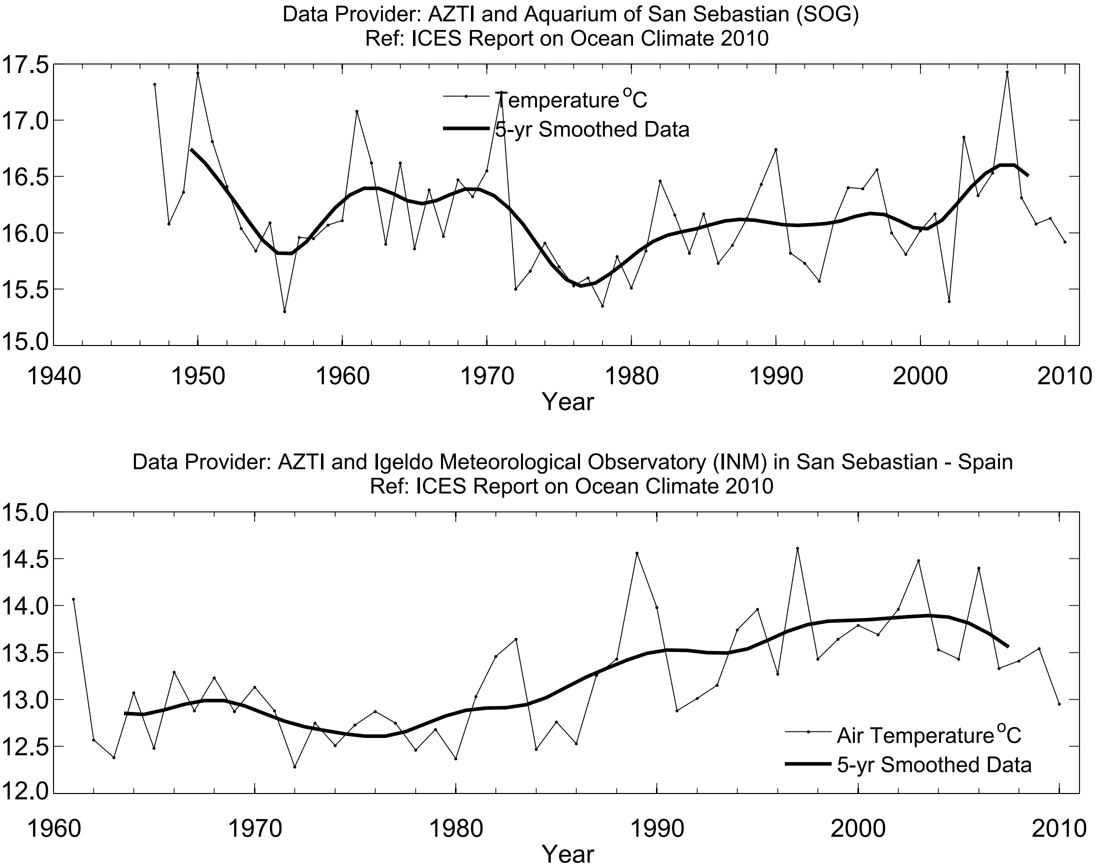


Figure 36 .
Area 4 – Bay of Biscay and eastern North Atlantic. Sea surface temperature (upper panel) and air temperature (lower panel) at San Sebastian (43.31°N 2.04°W).

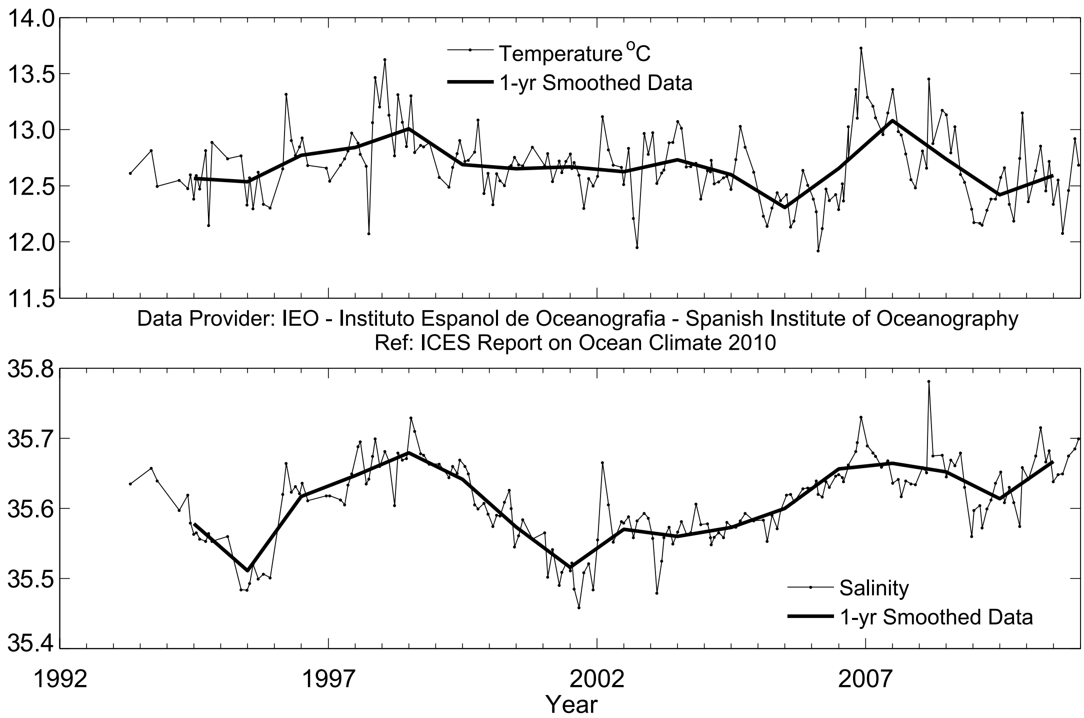


Figure 37 .
Area 4 – Bay of Biscay and eastern North Atlantic. Potential temperature (upper panel) and salinity (lower panel) at Santander Station 6 (5–300 m).

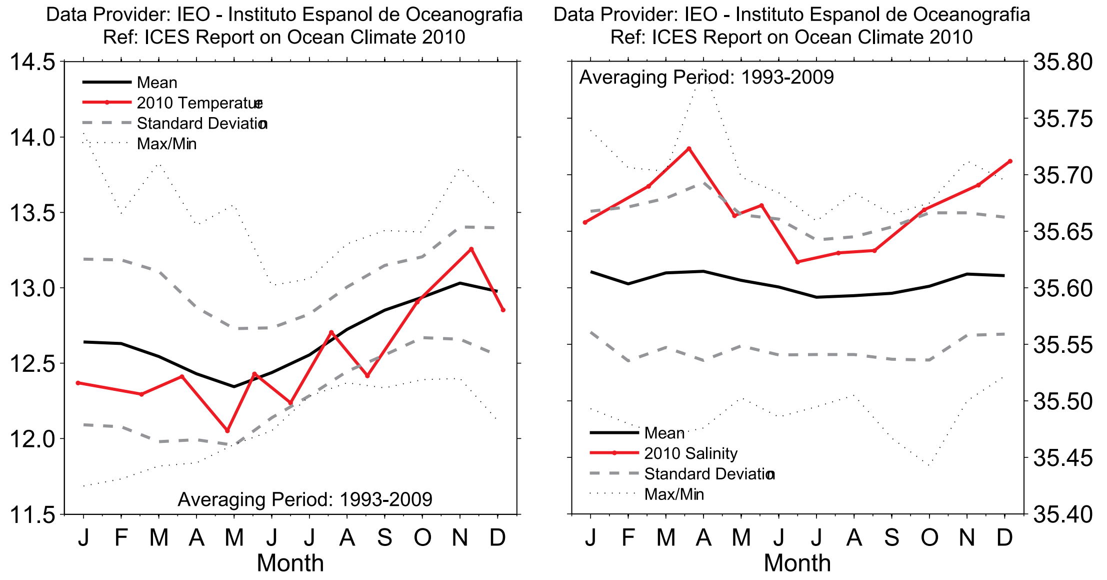


Figure 38.
Area 4 – Bay of Biscay and eastern North Atlantic. 2010 monthly temperature (left panel) and salinity (right panel) at Santander Station 6 (5–300 m).

4.8 Area 4b – Northwest European continental shelf

North coast of Brittany

MEASUREMENTS ARE COLLECTED TWICE A MONTH AT A COASTAL STATION ON THE NORTH COAST OF BRITTANY, FRANCE. THE ASTAN SITE (48.77°N 3.94°W) IS LOCATED 3.5 KM OFFSHORE, AND MEASUREMENTS BEGAN IN 2000. PROPERTIES AT THIS SITE ARE TYPICAL OF THE WESTERN CHANNEL WATERS. BOTTOM DEPTH IS CA. 60 M, AND THE WATER COLUMN IS WELL MIXED FOR MOST OF THE SURVEYS.

Temperatures during 2010 were lower than the mean (lowest since 1994). Between January and March, temperatures were <–1.0°C lower than the average. Throughout spring and early summer, temperatures remained lower than average. Temperatures were close to the average in August and September, but lower than average again in December. In 2010, the salinity annual cycle was characterized by a spring minimum (–0.014 in April). Salinity was slightly higher than average during summer, but slightly lower than average during autumn and early winter. During spring and summer 2010, Western Channel waters were generally well mixed over the entire water column because no temperature differences between surface and bottom waters were observed. A low vertical temperature gradient ($\Delta T = 0.4°C$) was episodically observed in late summer during a sunny neap-tide period.

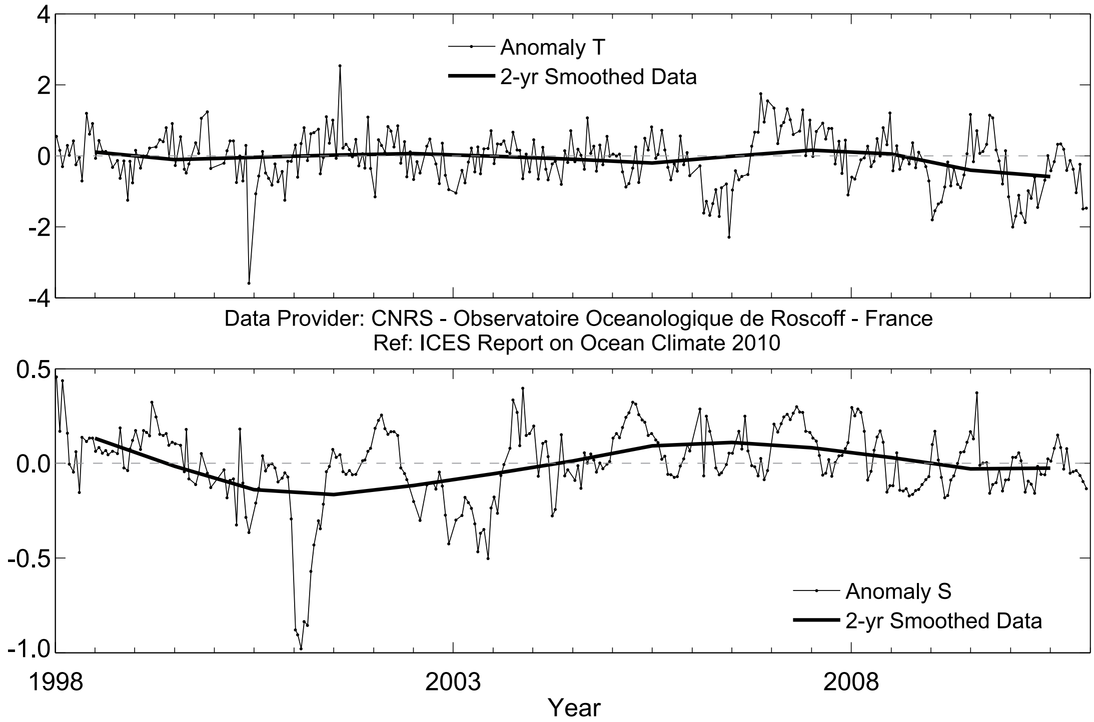


Figure 39.
Area 4b – Northwest European continental shelf. Temperature anomalies (upper panel) and salinity anomalies (lower panel) of surface water at the Astan station (48.77°N 3.94°W).

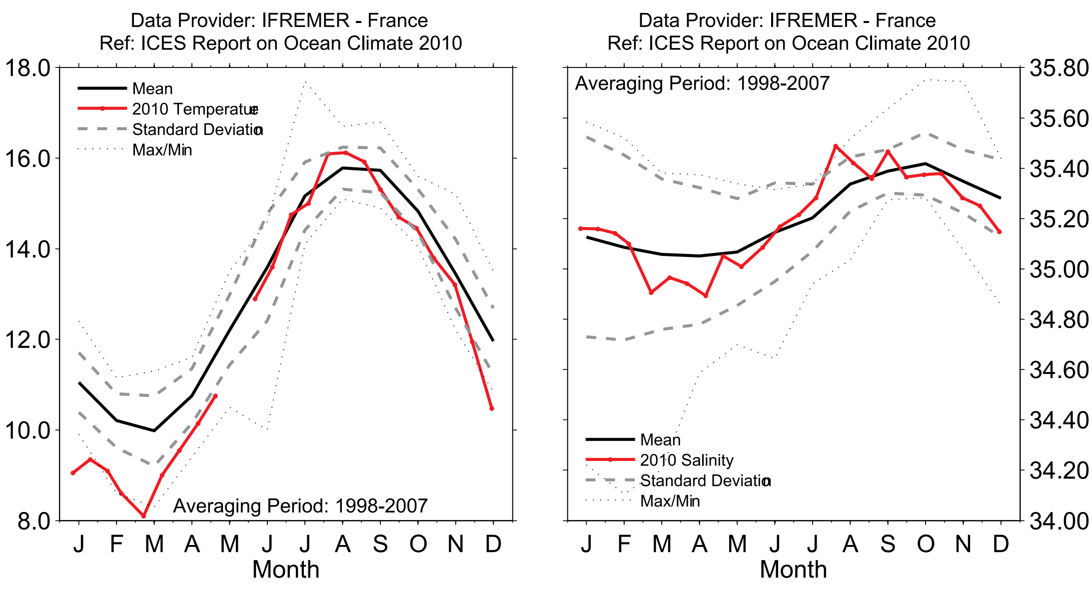


Figure 40.
Area 4b – Northwest European continental shelf. 2010 monthly temperature (left panel) and salinity (right panel) of surface water at the Astan station (48.77°N 3.94°W).

Western English Channel

Station E1 (50.03°N 4.37°W) is situated in the western English Channel and is mainly influenced by North Atlantic Water. The water depth is 75 m, and the station is tidally influenced by a 1.1-knot maximum surface stream at mean spring tide. The seabed is mainly sand, resulting in a low bottom stress (1–2 ergs cm^{-2} s^{-1}). The station may be described as oceanic with the development of a seasonal thermocline; stratification typically starts in early April, persists throughout summer, and is eroded by the end of October. The typical depth of the summer thermocline is around 20 m. The station is greatly affected by ambient weather.

Measurements have been taken at this station since the end of the 19th century, with data currently available since 1903. The series is unbroken, apart from the gaps for the two world wars and a hiatus in funding between 1985 and 2002. The data takes the form of vertical profiles of temperature and salinity. Early measurements were taken with reversing mercury-in-glass thermometers and discrete salinity bottles. More recently, electronic equipment (Seabird CTD) has been utilized.

The time-series demonstrates considerable interannual variability in temperature. In 2010, Station E1 was sampled on 12 occasions, with no sampling occurring during February and May. The minimum recorded surface temperature (March) was 8.4°C, and the maximum surface temperature (June) was 17.6°C. It was a year of two halves as far as the surface temperatures were concerned with the winter and spring temperatures being below and around average, but the summer and autumn temperatures being above the long-term mean. The 50 m temperature series show that the water was cooler by about a degree than the long-term average for the year until October. The salinity record over the year showed at both the surface and 50 m that the water column was more saline than average by approximately 0.1. This was particularly marked in the autumn period.

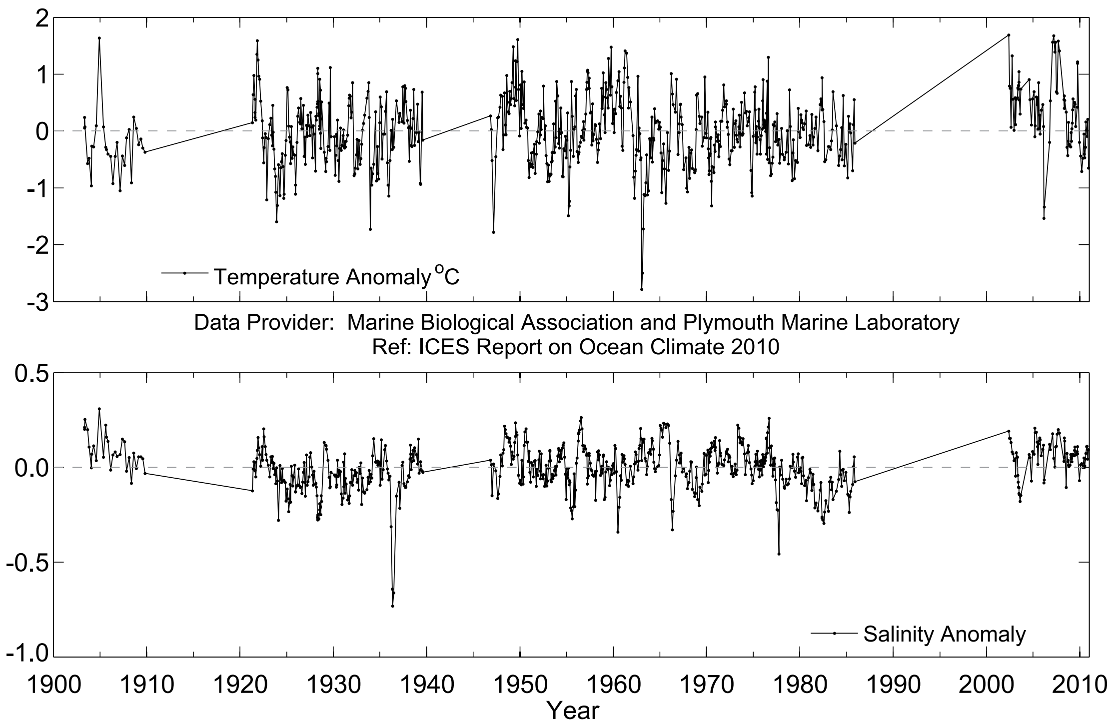


Figure 41.
Area 4b – Northwest European continental shelf. Temperature anomalies (upper panel) and salinity anomalies (lower panel) of surface water at Station E1 in the western English Channel (50.03°N 4.37°W).

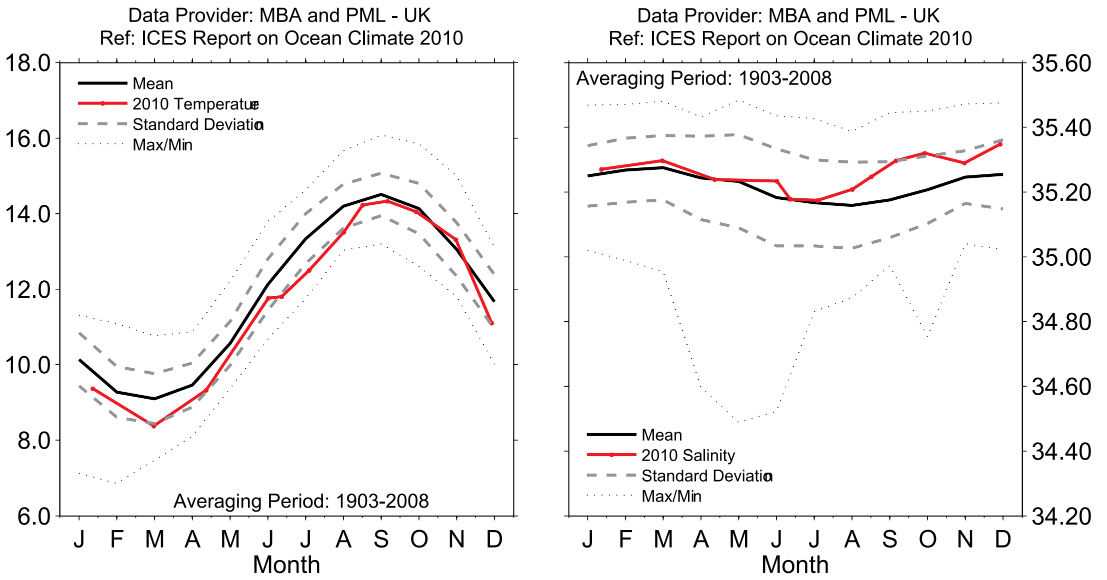


Figure 42.
Area 4b – Northwest European continental shelf. 2010 monthly temperature (left panel) and salinity (right panel) of surface water at Station E1 in the western English Channel (50.03°N 4.37°W).

North and southwest of Ireland

THE TIME-SERIES OF SURFACE OBSERVATIONS AT THE MALIN HEAD COASTAL STATION (THE MOST NORTHERLY POINT OF IRELAND) IS INSHORE OF COASTAL CURRENTS AND INFLUENCED BY RUN-OFF. AN OFFSHORE WEATHER BUOY HAS BEEN MAINTAINED AT 51.22°N 10.55°W OFF THE SOUTHWEST COAST OF IRELAND SINCE MID-2002, WHERE SEA SURFACE TEMPERATURE DATA ARE COLLECTED HOURLY.

At Malin Head, sea surface temperatures have been increasing since the late 1980s, and those for the mid-2000s were the highest since records began in 1960. No data are available for 2010.

At the M3 buoy, there is considerable interannual variability, with the warmest recorded summer temperatures in 2003 and 2005, and the warmest winter temperatures in 2007. In 2010, temperatures were below the time-series mean (2003–2009) in the early months of the year, recovering to near-normal levels by early summer. Late summer and early autumn temperatures were higher than the mean, whereas temperatures decreased in line with adversely cold weather conditions in November and December 2010.

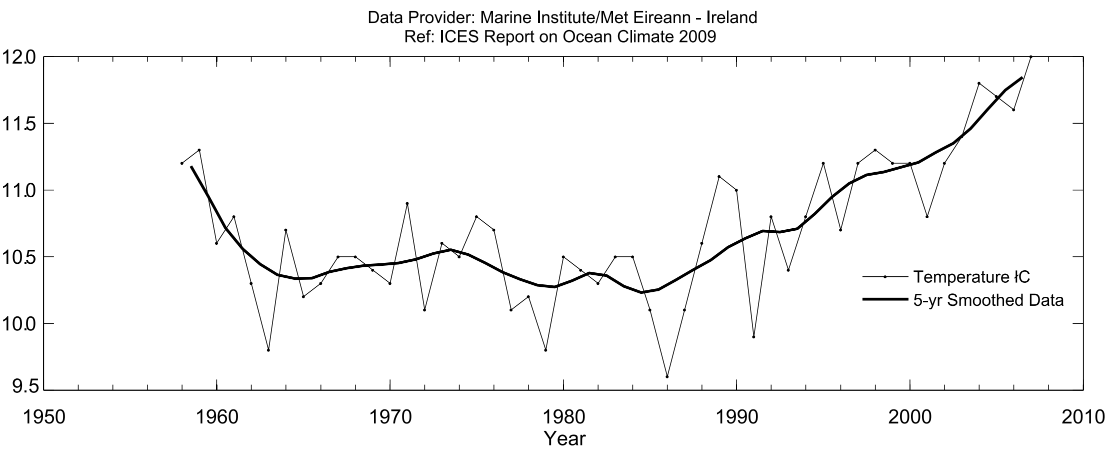


Figure 43.
Area 4b – Northwest European continental shelf. Temperature at the Malin Head coastal station (55.39°N 7.38°W).

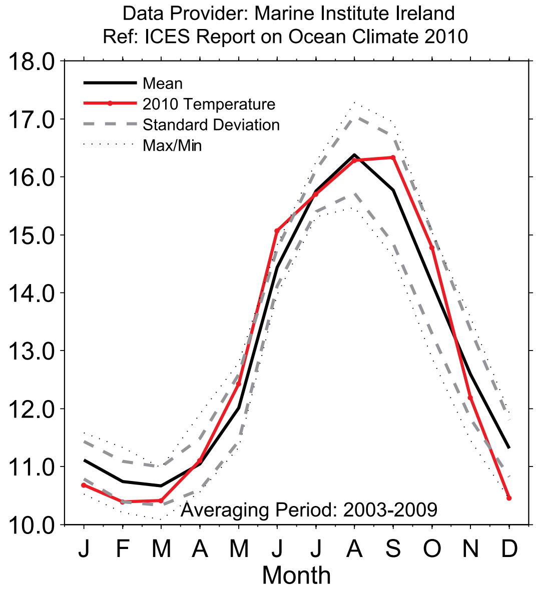


Figure 44.
Area 4b – Northwest European continental shelf. 2010 monthly temperature at the M3 Weather Buoy southwest of Ireland (51.22°N 10.55°W). No salinity data were collected at this station.

4.9 Area 5 – Rockall Trough

THE ROCKALL TROUGH IS SITUATED WEST OF BRITAIN AND IRELAND AND IS SEPARATED FROM THE ICELAND BASIN BY HATTON AND ROCKALL BANKS, AND FROM THE NORDIC SEAS BY THE SHALLOW (500 M) WYVILLE–THOMSON RIDGE. IT ALLOWS WARM NORTH ATLANTIC UPPER WATER TO REACH THE NORWEGIAN SEA, WHERE IT IS CONVERTED INTO COLD, DENSE OVERFLOW WATER AS PART OF THE THERMOHALINE OVERTURNING IN THE NORTH ATLANTIC. THE UPPER WATER COLUMN IS CHARACTERIZED BY POLEWARD-MOVING EASTERN NORTH ATLANTIC WATER, WHICH IS WARMER AND MORE SALINE THAN WATERS OF THE ICELAND BASIN, WHICH ALSO CONTRIBUTE TO THE NORDIC SEA INFLOW.

Temperature and salinity of the upper 800 m of the Rockall Trough remain high. The most recent measurements, made in May 2010, indicate that salinity has remained nearly constant for the past seven years, following the record level reached in 2003. Temperature is also high but is now undergoing a steady decrease, totalling 0.5°C over the past four years, since the peak in October 2006.

TEMPERATURE AND SALINITY OF THE UPPER 800 M OF THE ROCKALL TROUGH REMAIN HIGH.

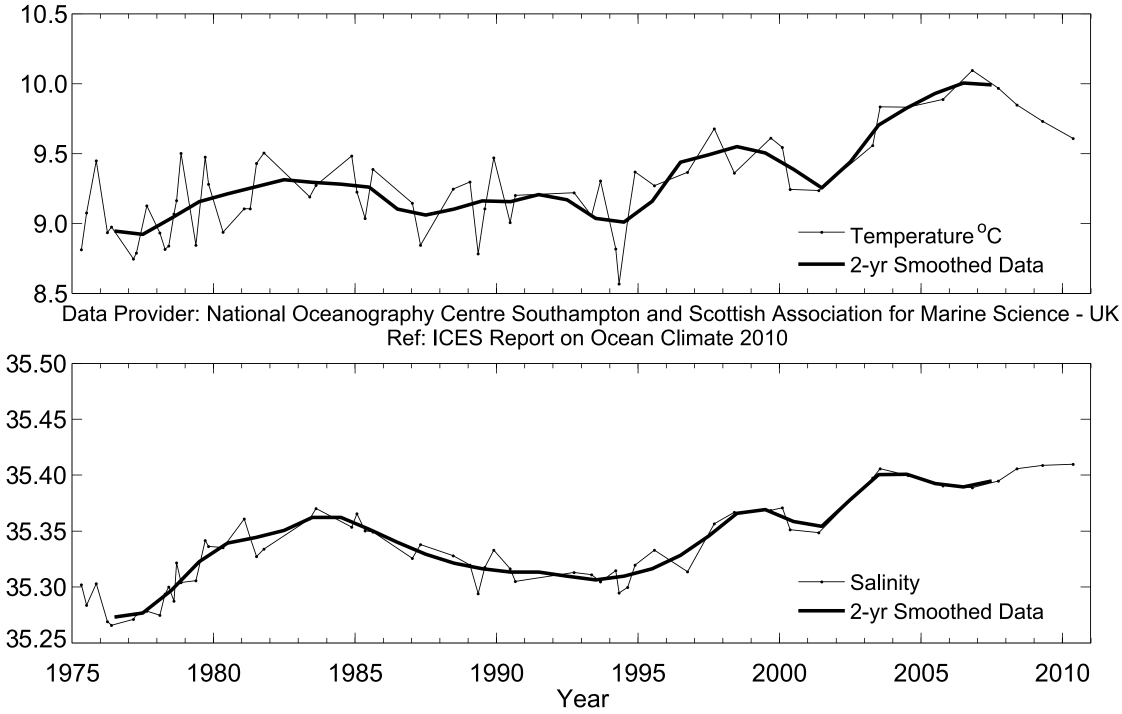


Figure 45.
Area 5 – Rockall Trough. Temperature (upper panel) and salinity (lower panel) for the upper ocean (0–800 m).

4.10 Area 5b – Irminger Sea

THE IRMINGER SEA IS THE OCEAN BASIN BETWEEN SOUTHERN GREENLAND, THE REYKJANES RIDGE, AND ICELAND. THIS AREA FORMS PART OF THE NORTH ATLANTIC SUBARCTIC ANTICYCLONIC GYRE. AS A RESULT OF THIS GYRE, THE EXCHANGE OF WATER BETWEEN THE IRMINGER SEA AND THE LABRADOR SEA IS RELATIVELY FAST. THE IRMINGER SEA IS INFLUENCED BY WARM SALINE WATER COMING FROM THE ICELAND BASIN, WHICH REACHES THE NORTHERN BASIN FIRST.

In 2004, the Subpolar Mode Water (SPMW) in the centre of the Irminger Sea, in the pressure interval 200–400 dbar, reached its highest temperature and salinity since 1991. Since then, a slight cooling and freshening has occurred, related to a lack of convective activity. In winter 2007/2008, convection in the SPMW reached depths of at least 1000 m, resulting in a temperature decrease of nearly 1°C and a salinity decrease of 0.03 from 2007 to 2008, similar to the SPMW change observed after the cold winter of 1999/2000. In 2010, the temperature of the SPMW rose again to more than 4.6°C, and salinity increased to 34.94.

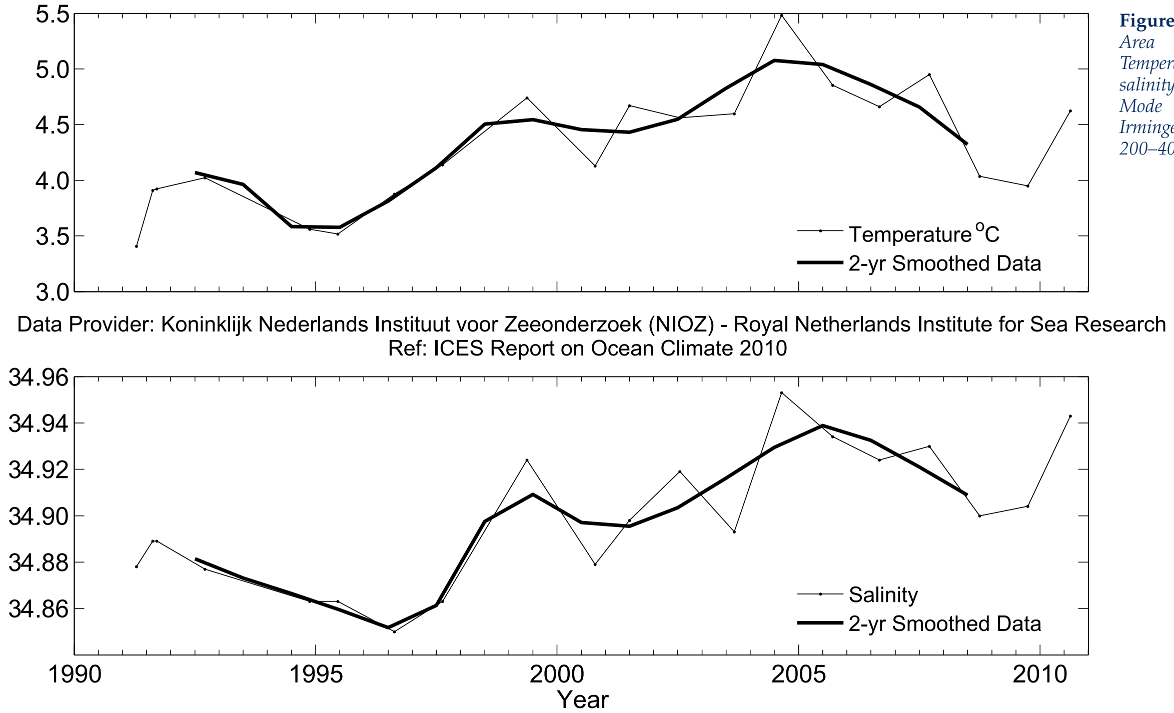


Figure 46.
Area 5b – Irminger Sea. Temperature (upper panel) and salinity (lower panel) of Subpolar Mode Water in the central Irminger Sea (averaged over 200–400 m).

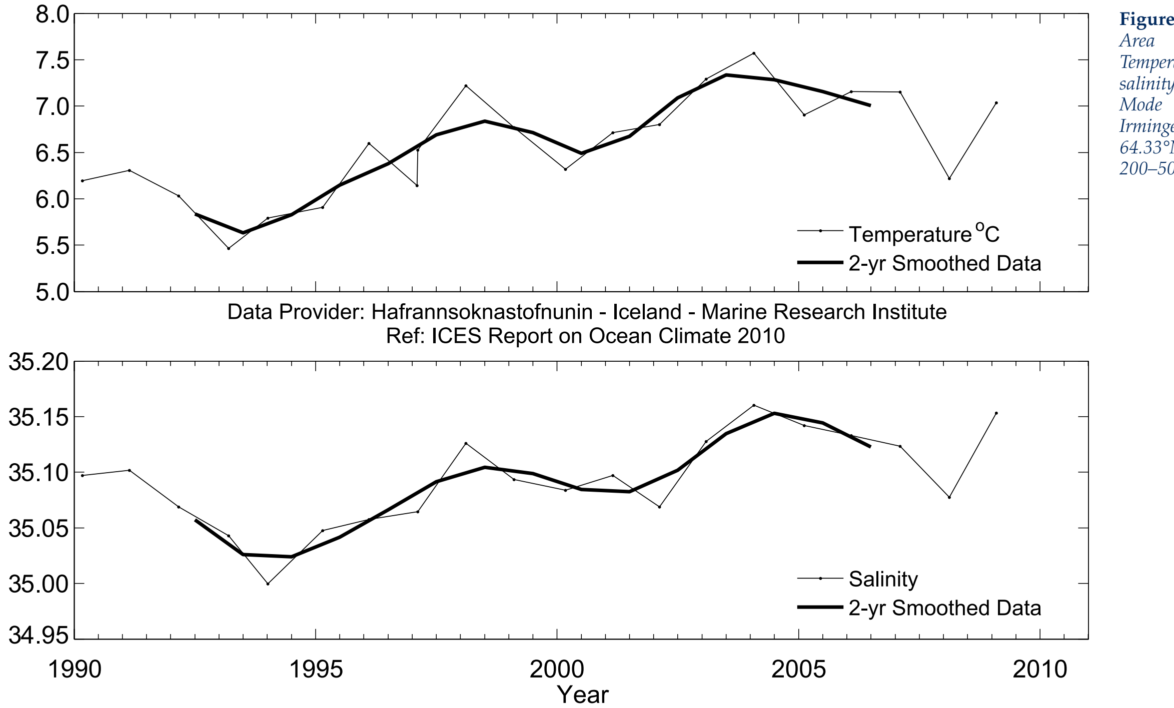


Figure 47.
Area 5b – Irminger Sea. Temperature (upper panel) and salinity (lower panel) of Subpolar Mode Water in the northern Irminger Sea (Station FX9, 64.33°N 28°W), averaged over 200–500 m).

4.11 Areas 6 and 7 – Faroe and Faroe–Shetland Channel

ONE BRANCH OF THE NORTH ATLANTIC CURRENT CROSSES THE GREENLAND–SCOTLAND RIDGE, FLOWING ON EITHER SIDE OF THE FAROES. ITS PROPERTIES ARE SAMPLED BY THE FAROE BANK CHANNEL BEFORE IT CROSSES THE RIDGE, AND BY THE FAROE CURRENT AFTER IT CROSSES THE RIDGE. SOME OF THIS WATER RECIRCULATES AND IS SAMPLED WITHIN THE FAROE–SHETLAND CHANNEL AS MODIFIED NORTH ATLANTIC WATER (MNAW). FARTHER TO THE EAST, THE CONTINENTAL SLOPE CURRENT FLOWS ALONG THE EDGE OF THE NORTHWEST EUROPEAN CONTINENTAL SHELF; ORIGINATING IN THE SOUTHERN ROCKALL TROUGH. IT CARRIES WARM, SALINE NORTH ATLANTIC WATER (NAW) INTO THE FAROE–SHETLAND CHANNEL.

A PROPORTION OF THE ATLANTIC WATER (AW) FLOWING THROUGH THE FAROE–SHETLAND CHANNEL CROSSES ONTO THE SHELF ITSELF AND ENTERS THE NORTH SEA, WHERE IT IS DILUTED WITH COASTAL WATER AND EVENTUALLY LEAVES IN THE NORWEGIAN COASTAL CURRENT. THE REMAINDER ENTERS THE NORWEGIAN SEA AND JOINS THE WATER COMING FROM NORTH OF THE FAROES TO BECOME THE NORWEGIAN AW.

Waters on the Faroe Shelf were warmer than normal throughout 2010. In the early part of the year (January–April), temperatures were more than 1 standard deviation higher than mean conditions. Summer temperatures were high but lower than the record-high values observed in 2009. Like all coastal and shelf time-series, this was affected by atmospheric and terrestrial effects, and it is clear that the very cold conditions experienced during December 2010 on the European continental shelf were not seen in the Faroe region.

The longer time-series of the Faroe–Shetland Channel reveal that the very low values of salinity recorded during 1975–1980 have generally increased since then. Both temperature and salinity in all waters around Faroe and the Faroe–Shetland Channel have increased markedly during the 1990s and 2000s.

In the Faroe region, high salinities were observed in 2009 and 2010, whereas temperatures remained slightly lower than those in the early 2000s.

The temperature of North Atlantic Water (NAW) in the Faroe–Shetland Channel has decreased a little from the very high values observed in 2003/2004, and the salinity of this water also decreased.

The water on the western slopes of the Channel, known as Modified North Atlantic Water (MNAW), reached record-high levels of temperature and salinity in 2009 and then increased again in 2010. This water travelled north of Faroe before entering the Faroe–Shetland Channel and exhibited a trend in salinity similar to that of the Faroe Current data.

It should be noted that the data for NAW and MNAW are from a single survey in 2010, and the exact values may need to be revised when further data becomes available.

WATERS ON THE FAROE SHELF DURING 2010 WERE WARMER THAN NORMAL ALL YEAR.

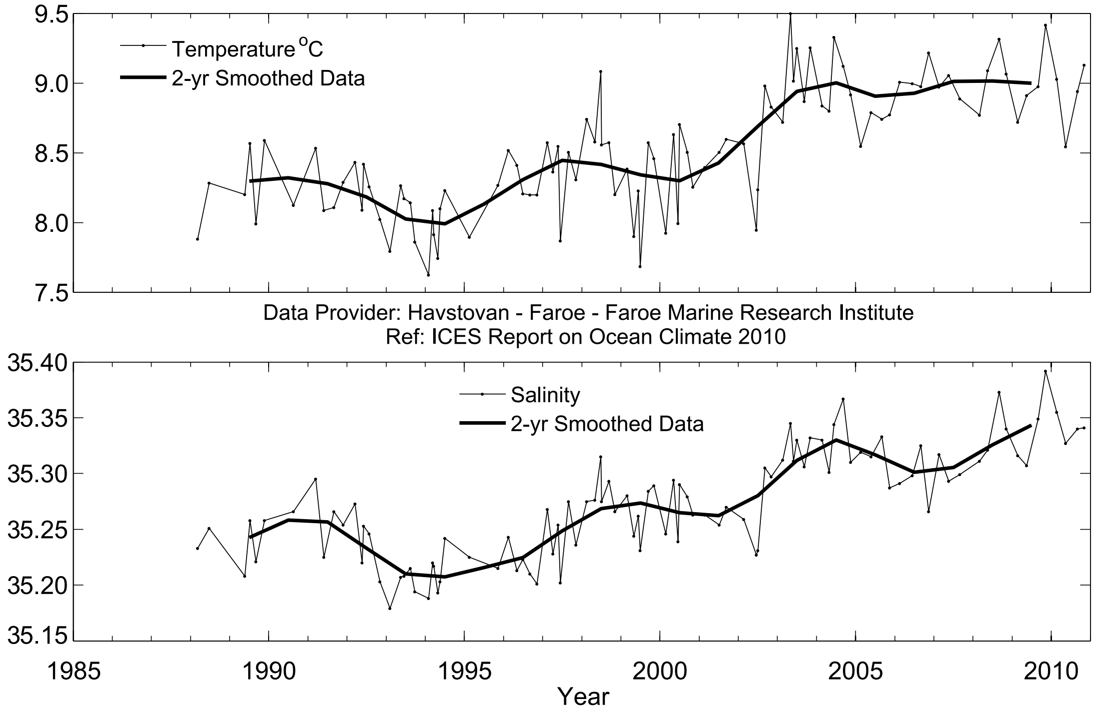


Figure 48.
Areas 6 and 7 – Faroe Bank Channel and Faroe Current. Temperature anomaly (upper panel) and salinity anomaly (lower panel) in the Atlantic Water in the Slope Current.

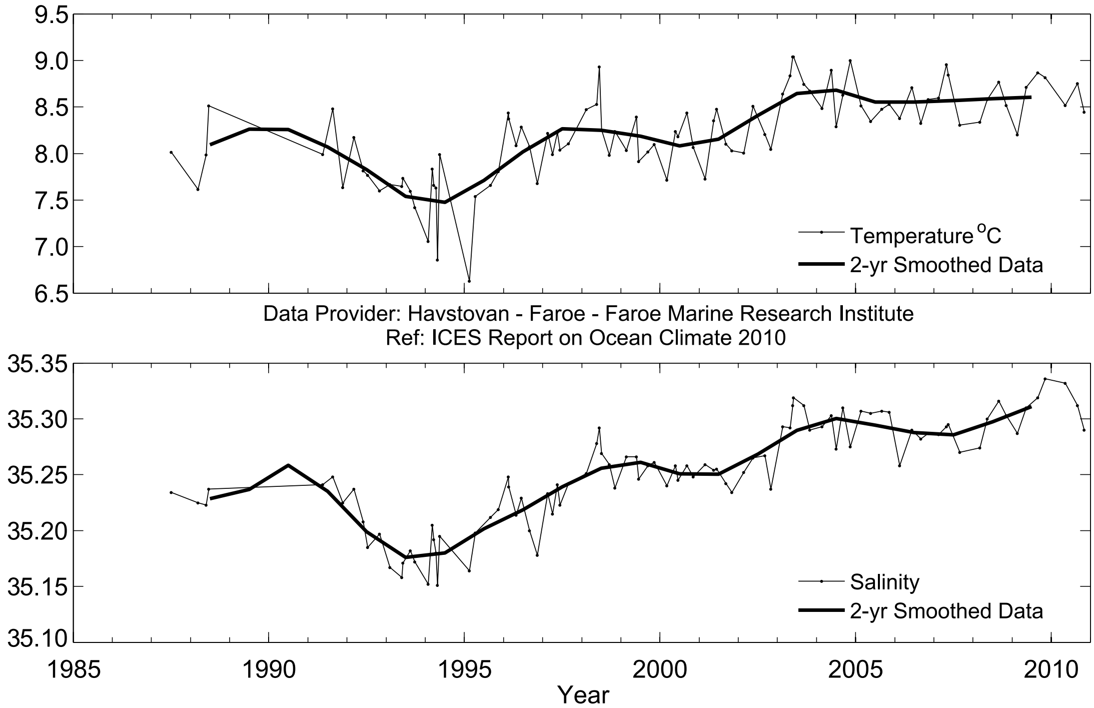


Figure 49.
Areas 6 and 7 – Faroe Bank Channel and Faroe Current. Temperature (upper panel) and salinity (lower panel) in the core of the Faroe Current (maximum salinity averaged over a 50 m deep layer).

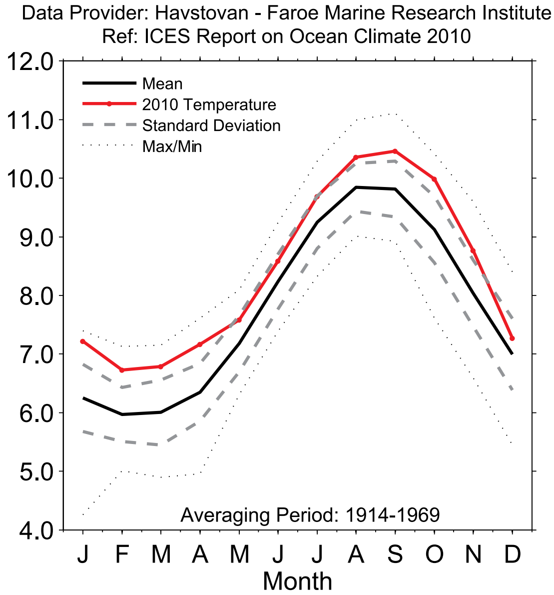


Figure 50.
Areas 6 and 7 – Faroe Bank Channel and Faroe Current. 2010 monthly temperature data from the Faroe coastal station at Oyrargjogv (62.12°N 7.17°W). Note the average values were calculated from the nearby station at Mykines (69.10°N 7.66°W).

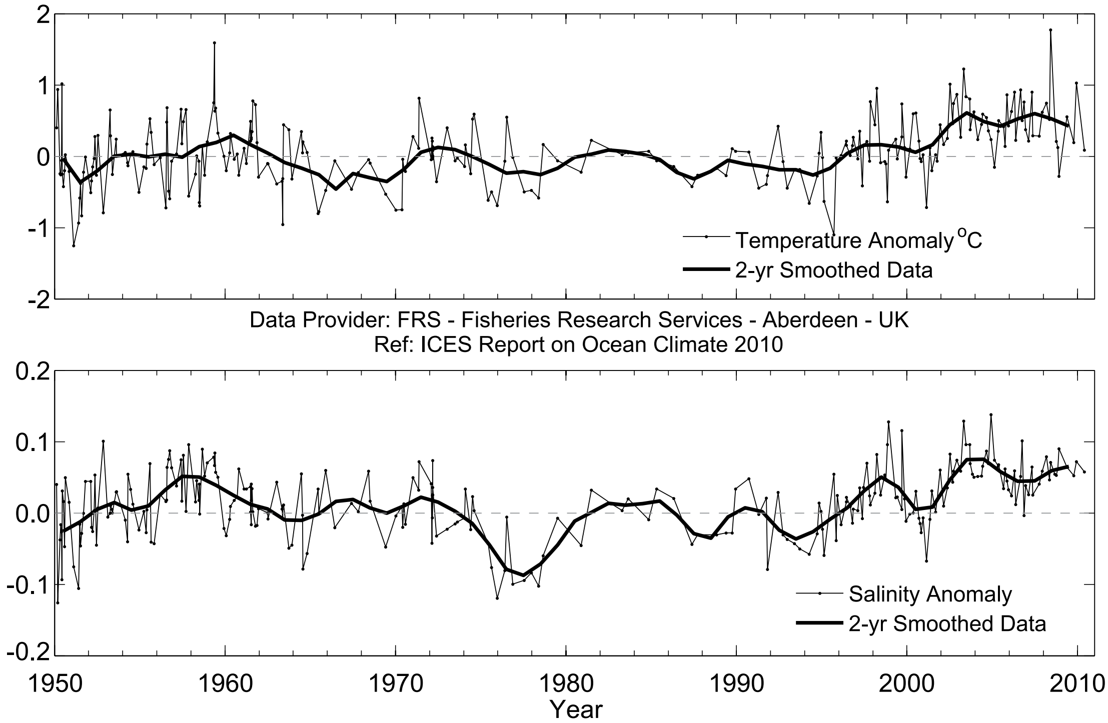


Figure 51.
Areas 6 and 7 – Faroe–Shetland Channel. Temperature anomaly (upper panel) and salinity anomaly (lower panel) in the Atlantic Water in the Slope Current.

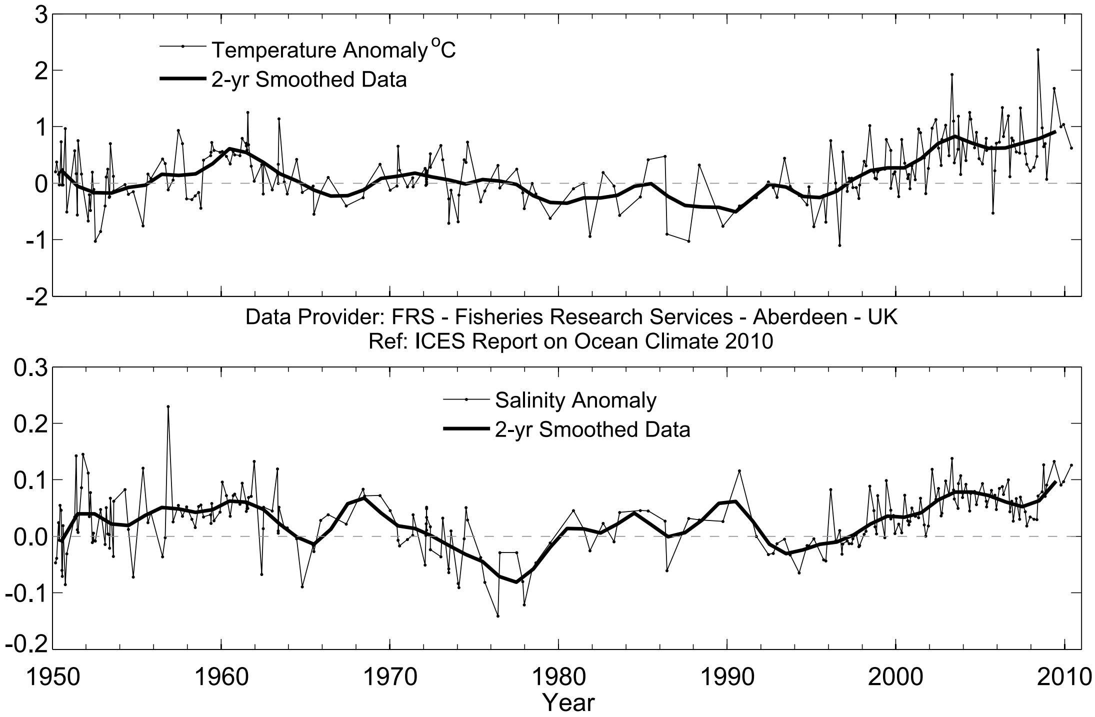


Figure 52.
Areas 6 and 7 – Faroe–Shetland Channel. Temperature anomaly (upper panel) and salinity anomaly (lower panel) in the Modified North Atlantic Water entering the Faroe–Shetland Channel from the north after circulating around the Faroe Islands.

Image courtesy of N. P. Holliday, National Oceanography Centre, UK.

4.12 Areas 8 and 9 – Northern and southern North Sea

North Sea oceanographic conditions are determined by the inflow of saline Atlantic Water (AW) and the ocean–atmosphere heat exchange. The inflow through the northern entrances (and, to a lesser degree, through the English Channel) can be strongly influenced by the NAO. Numerical model simulations also demonstrate strong differences in the North Sea circulation, depending on the state of the NAO. The AW mixes with river run-off and lower salinity Baltic outflow along the Norwegian coast. A balance of tidal mixing and local heating forces the development of a seasonal stratification from April/May to September in most parts of the North Sea.

Autumn 2009 was marked by unusually warm sea surface temperatures (SSTs) until December, but after the severe 2009/2010 winter, the SST dropped below the reference mean (1971–1993) in January–March 2010, with anomalies between −0.3° and −0.6°C. During this period, the North Sea was characterized by positive anomalies in the northwestern part (inflow of warmer Atlantic Water (AW)) and negative anomalies along the east coasts after the severe continental winter. This pattern was also observed in May and June, whereas, in April, there were positive anomalies over large areas of the North Sea, with high solar radiation values. In summer, temperature anomalies were +0.2° to +0.8°C. The SST dropped rapidly during December 2010, resulting in an anomaly of −0.8°C. The annual averaged anomaly was +0.1°C cooler than in 2009 (+0.8°C). Apart from the inflow of warmer AW at the northern boundary and through the English Channel, most of the SST variability was caused by local ocean–atmosphere heat flux.

In general, the late summer horizontal temperature distribution of the surface and bottom layers was comparable with 2009, with isotherms running approximately southwest–northeast. The ribbon of warm, vertically mixed water along the continental coast was smaller and ca. 1°C cooler than in 2009. The difference between the surface and bottom temperatures in the central North Sea increased by ca. 2°C to ca. 10°C compared with 2009. The thermocline depth varied between 20 and 30 m compared with more than 40 m in 2009. The thermocline is generally very smooth; the maximum gradients exceeded 1.5°C m^{-1} in small areas only. A sharp thermocline was observed east of Dogger Bank. The sharpness of the thermocline gradually decreased north of 56°N. The thermocline above the Norwegian Trench, at ca. 7°E on the 58°N section, was locally depressed to ca. 50 m depth.

The colder bottom layer occupied a greater volume, with the tongue of 8°C water reaching far to the south (55°N). This is also evident in the total heat content of the North Sea, which integrates the effects of solar radiation, advection of AW, seasonal stratification, and atmospheric heat exchange. In 2010, the total heat content was 1.515×10^{21} J, the lowest value since 2002. The standard deviation (s.d.) of the total heat content for the reference period amounts to ca. 5% of the mean value.

The late-summer salinity concentrations in the surface and bottom layers were very similar to 2009; in both years, the 35 isohaline intruded from the north to close to 56°N. The ribbon of fresher water (<34) parallel with the continental coast was a little broader than in 2009, close to the average position for the 1998–2010 period. The bottom salinity south of 56°N was generally higher than in 2009 and less patchy. The zonal salinity sections exhibited a very homogeneous intrusion of highly saline water in the northwestern North Sea. In the southern North Sea, the vertical structure was less patchy than in previous years. The total salt content during the 2010 survey was 1.141×10^{12} t, which is very close to the 2000–2009 average of 1.142×10^{12} t. The s.d. of the total salt content for the reference period amounts to only ca. 0.4% of the mean value.

During March and August–December, the monthly Elbe River run-off underwent a clear increase compared with the long-term mean. The annual averaged run-off of more than 30 km^3 $year^{-1}$ exceeded the long-term mean of ca. 20 km^3 $year^{-1}$; however, the value was still within the 95% confidence interval.

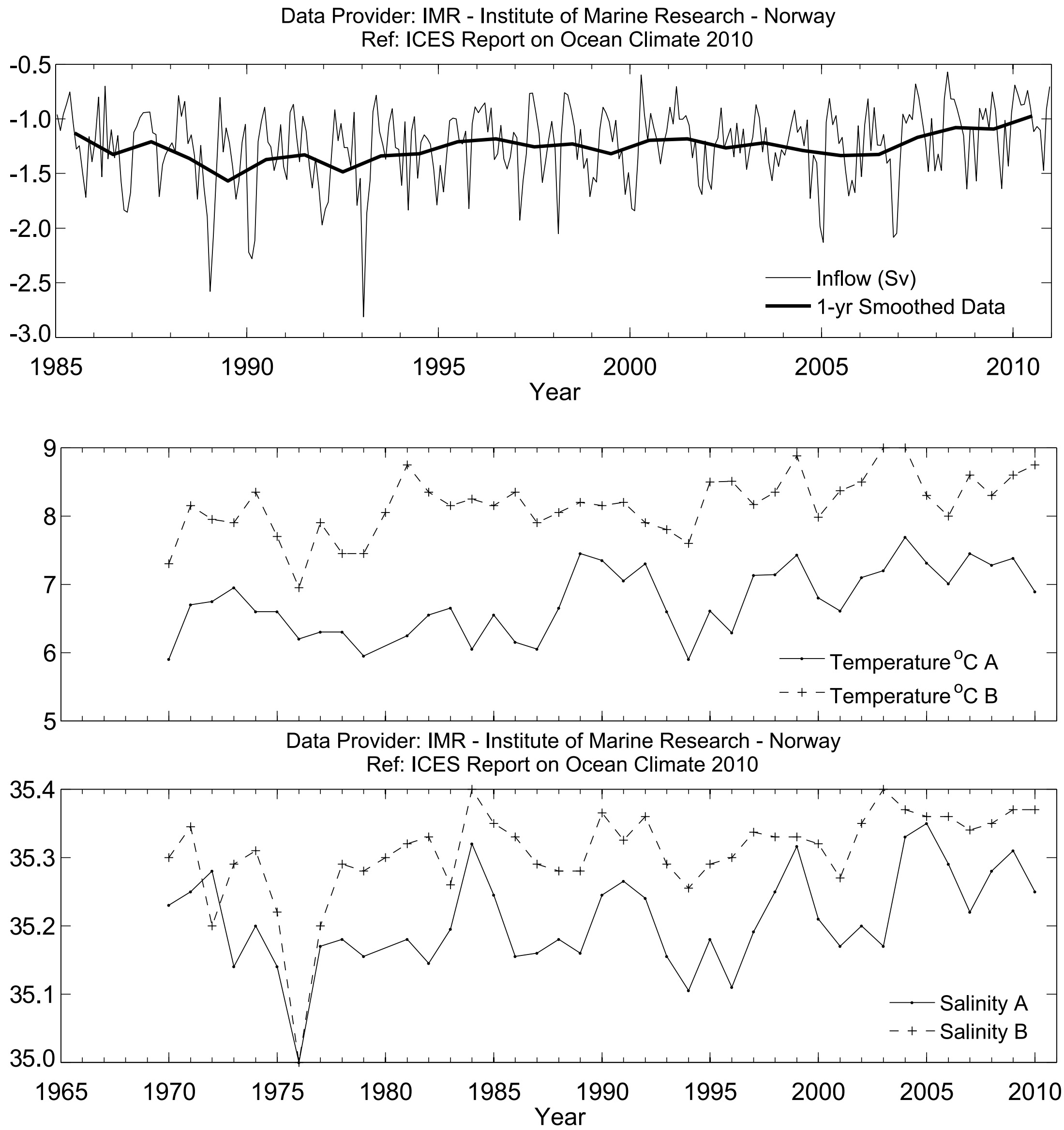


Figure 53.
Area 8 – Northern North Sea. Modelled annual mean (bold) and monthly mean volume transport of Atlantic Water (AW) into the northern and central North Sea southwards between the Orkney Islands and Utsire, Norway (top panel). Temperature (middle panel) and salinity (bottom panel) near the seabed in the northwestern part of the North Sea (Location A) and in the core of AW at the western shelf edge of the Norwegian Trench (Location B) during summers 1970–2007.

Figure 54.
Area 8 – Northern North Sea. Temperature anomaly (upper panel) and salinity anomaly (lower panel) in the Fair Isle Current entering the North Sea from the North Atlantic.

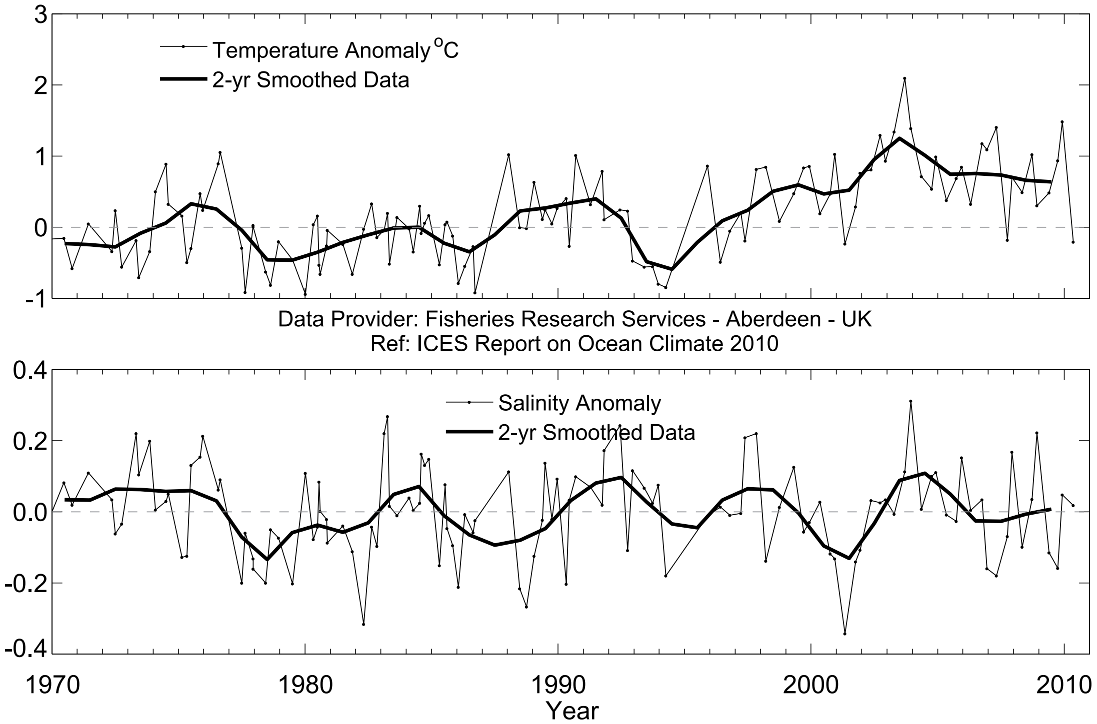
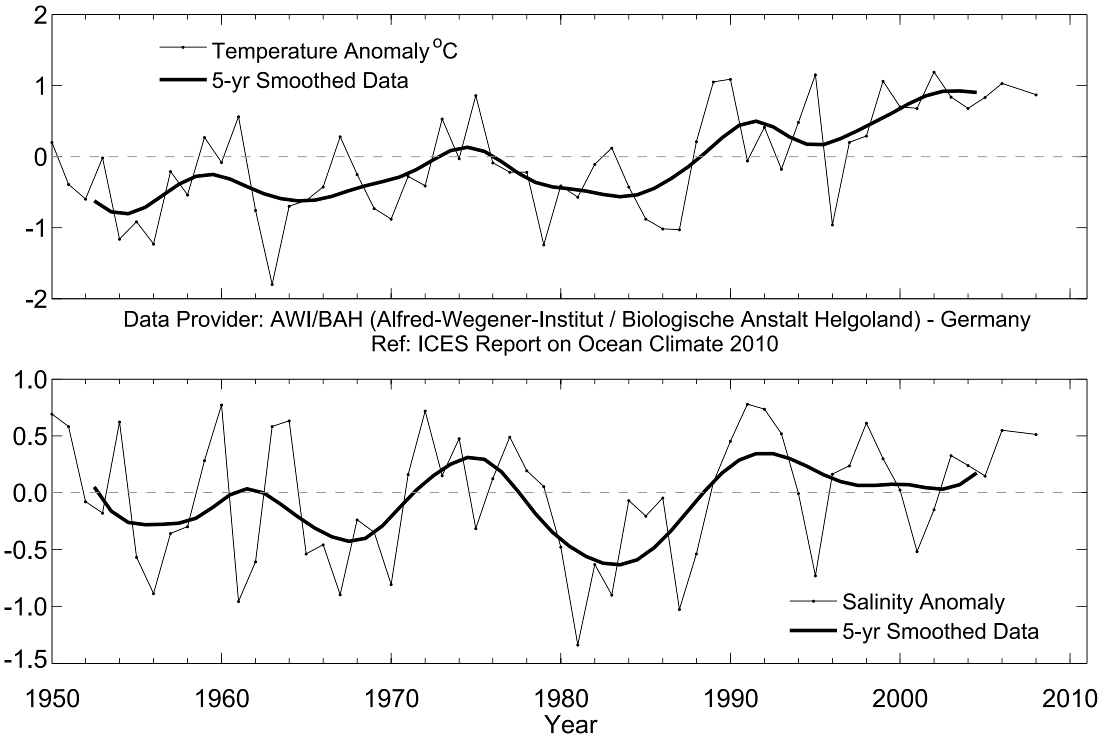


Figure 55.
Area 9 – Southern North Sea. Annual mean surface temperature anomaly (upper panel) and salinity anomaly (lower panel) at Station Helgoland Roads. Data reproduced from Wiltshire et al. *(2008).*



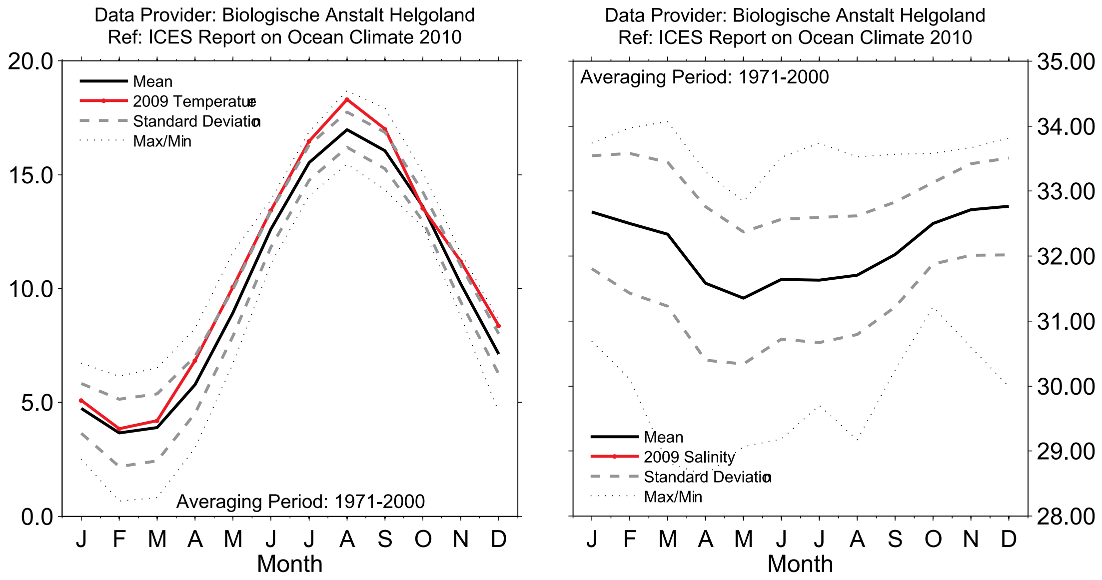


Figure 56.
Area 9 – Southern North Sea. 2010 monthly surface temperature (left panel) and salinity (right panel) at Station Helgoland Roads. Data reproduced from Wiltshire et al. (2008).

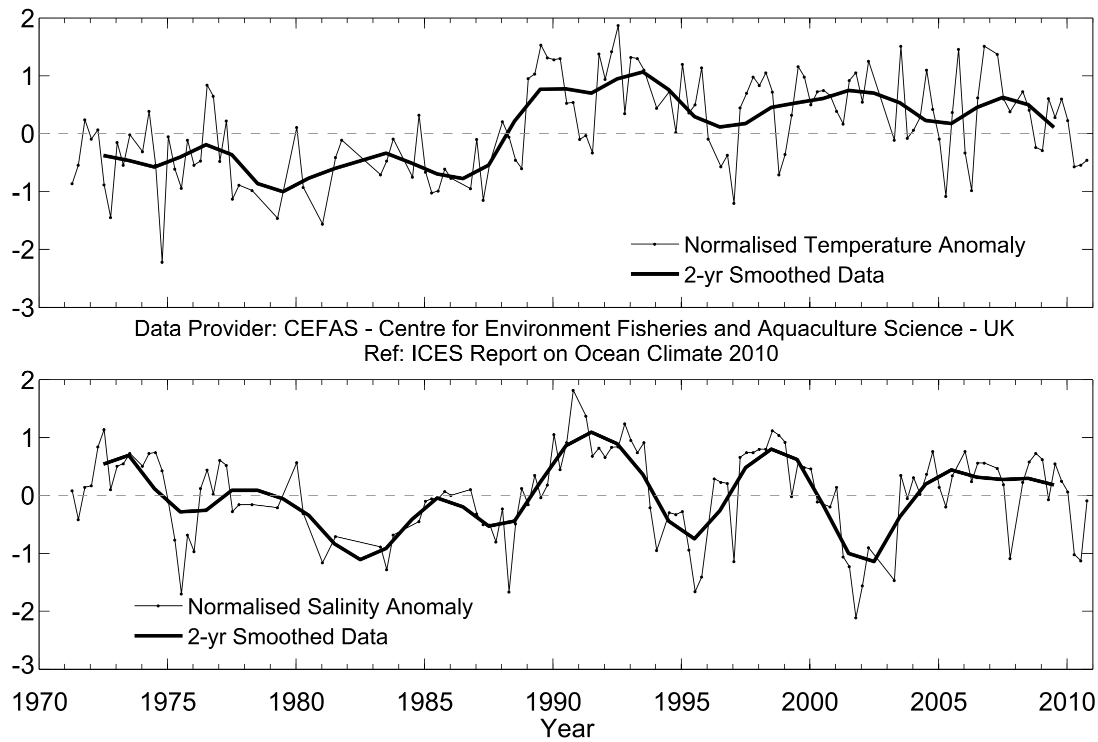


Figure 57.
Area 9 – Southern North Sea. Normalized sea surface temperature anomaly (upper panel) and salinity anomaly (lower panel) relative to 1971–2000, measured along 52°N by a regular ferry at six standard stations. The time-series reveals the seasonal section average (DJF, MAM, JJA, SON) of the normalized variable.

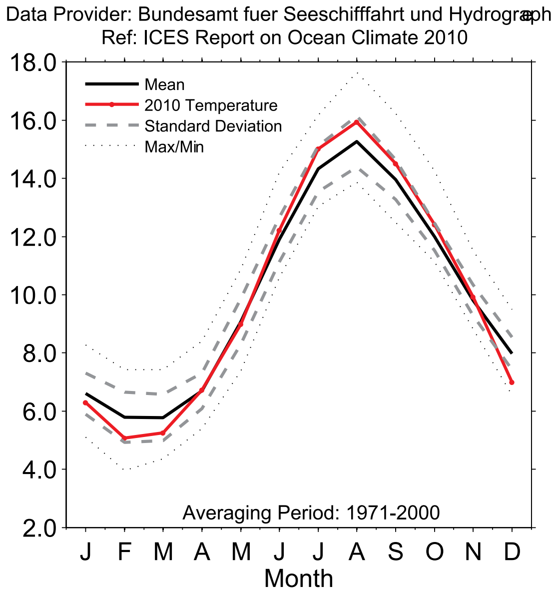


Figure 58. *Areas 8 and 9 – Northern and southern North Sea. North Sea area-averaged sea surface temperature (SST) annual cycle; 2010 monthly means based on operational weekly North Sea SST maps.*

4.13 Area 9b – Skagerrak, Kattegat, and the Baltic

THE SEAS IN AREA 9B ARE CHARACTERIZED BY LARGE SALINITY VARIATIONS. IN THE SKAGERRAK, WATER MASSES FROM DIFFERENT PARTS OF THE NORTH SEA ARE PRESENT. THE KATTEGAT IS A TRANSITION AREA BETWEEN THE BALTIC AND THE SKAGERRAK. THE WATER IS STRONGLY STRATIFIED, WITH A PERMANENT HALOCLINE (SHARP CHANGE IN SALINITY AT DEPTH). THE DEEP WATER IN THE BALTIC PROPER, WHICH ENTERS THROUGH THE BELTS AND THE SOUND, CAN BE STAGNANT FOR LONG PERIODS IN THE INNER BASINS. IN THE RELATIVELY SHALLOW AREA IN THE SOUTHERN BALTIC, SMALLER INFLOWS PASS RELATIVELY QUICKLY, AND THE CONDITIONS IN THE DEEP WATER ARE QUITE VARIABLE. SURFACE SALINITY IS VERY LOW IN THE BALTIC PROPER AND THE GULF OF BOTHNIA. THE LATTER AREA IS ICE COVERED DURING WINTER.

Owing to Sweden's central location relative to the Skagerrak, Kattegat, and Baltic, the weather there can be taken as representative for the area. In 2010, the weather was characterized as being more continental than maritime; with cold winter months and a period of very warm weather during summer. The mean air temperature was below normal almost everywhere in Sweden, and the average for the whole country was around 1°C below normal, which makes 2010 the coldest year since 1987, with the largest anomalies found in the western parts. The southern part of Sweden experienced the coldest December recorded for the past 100 years. Precipitation was, in general, above normal, with record depths of snow in the southern part of Sweden at the beginning of the year. The westerly and southwesterly winds were weaker and less frequent than normal in the southern part of Sweden, whereas the opposite was true for winds from the north and east, again reflecting the continental type of weather in 2010. The number of sun-hours was normal in most places.

In the Skagerrak, the surface temperature and salinity were well below normal during January and February. For the rest of the year, the values were close to normal. The surface temperature in the Kattegat was below normal in February and December and above normal in July. In January, February, and December, the surface salinity was below normal. The temperature in the surface waters was close to normal in the Baltic Proper for most of the year, except for June and July, which were warmer than normal, and December, which was colder. In the Bothnian Bay and Bothnian Sea, the surface temperature was well below normal in December. For the rest of the year, conditions in the northern Baltic Sea were close to normal, except for late May and July, when surface temperatures were exceptionally high.

The slight warming of the deep waters in the northern Baltic after 2004 seemed to have stopped in 2009 and 2010. There was a very slight increase in deep-water salinity, but the general salinity level was around the same as in the past 15 years.

There were several minor inflows into the Baltic during autumn, improving the oxygen conditions in deeper parts of the Arkona and Bornholm basins. However, for the Bornholm Basin, the effect of the inflows was not long-lasting and low oxygen values soon reappeared.

The 2009/2010 ice season was considered the most severe since 1987, with a maximum ice extent of more than twice that of the previous season. The maximum ice extent occurred on 17 February and, at that time, parts of the Skagerrak, Kattegat, and the Sounds were also ice covered.

COLD WINTER MONTHS AND ICE IN SKAGERRAK/KATTEGAT.

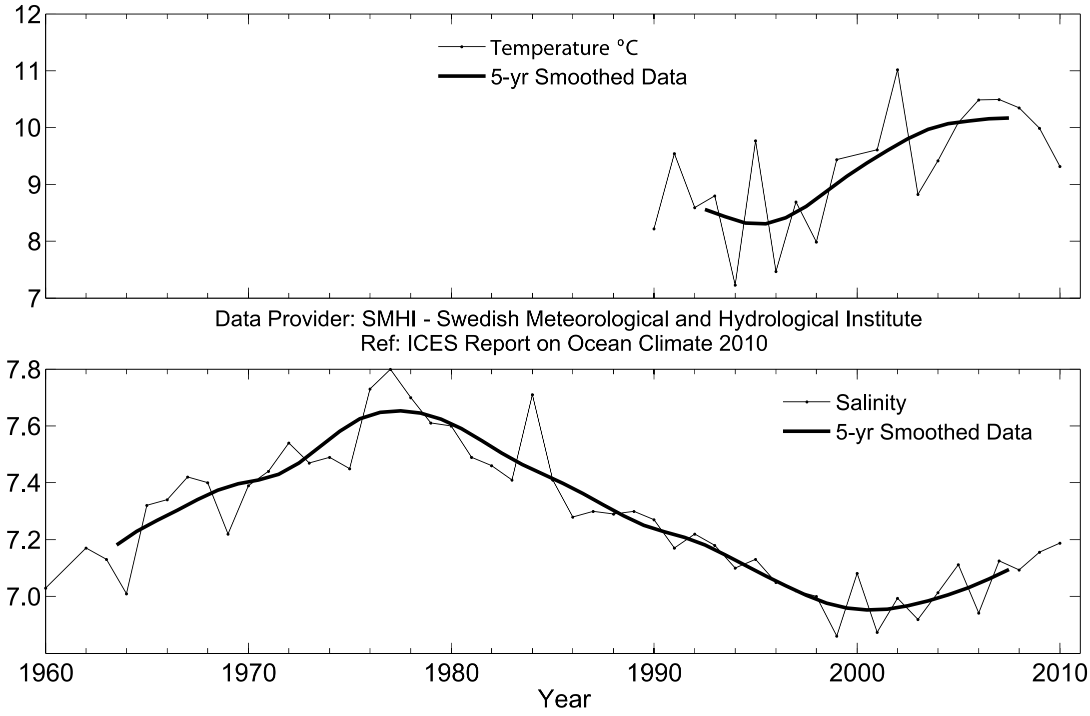


Figure 59.
Area 9b – Skagerrak, Kattegat, and the Baltic. Surface temperature (upper panel) and surface salinity (lower panel) at Station BY15 (east of Gotland) in the Baltic Proper.

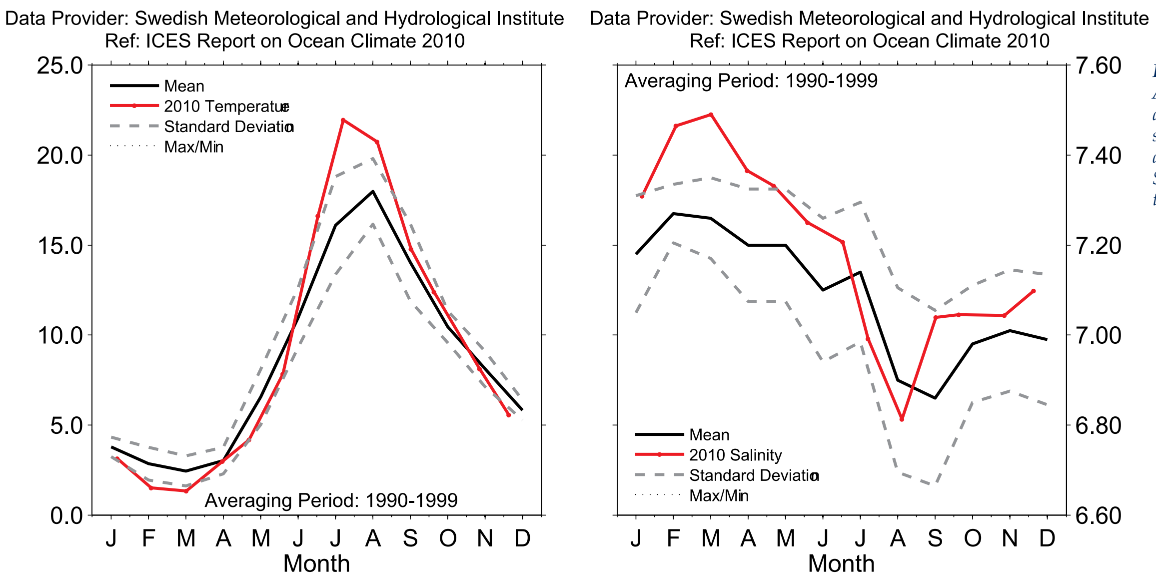
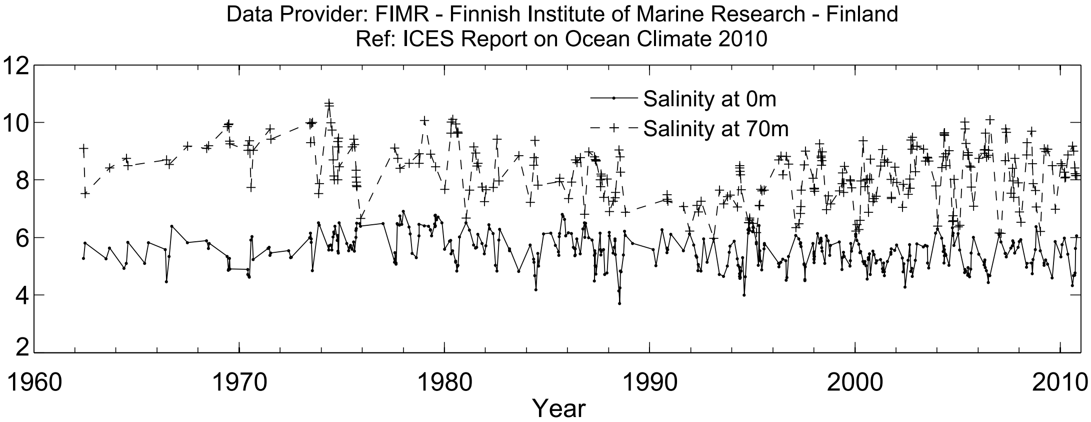


Figure 60.
Area 9b – Skagerrak, Kattegat, and the Baltic. 2010 monthly surface temperature (left panel) and salinity (right panel) at Station BY15 (east of Gotland) in the Baltic Proper.

__Figure 61.__
Area 9b – Skagerrak, Kattegat, and the Baltic. Salinity at Station LL7 in the Gulf of Finland (data to 2008; upper panel) and at Station B03 in Bothnian Bay (data to 2008; lower panel).



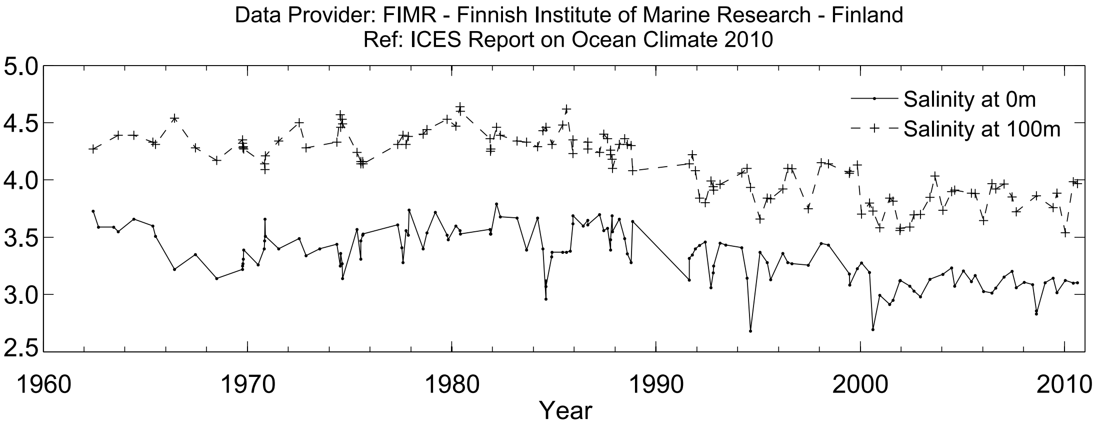
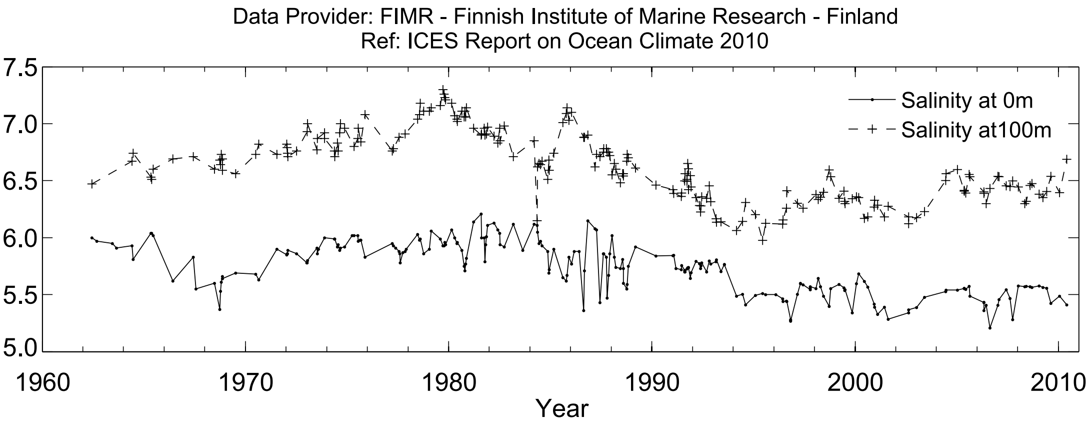
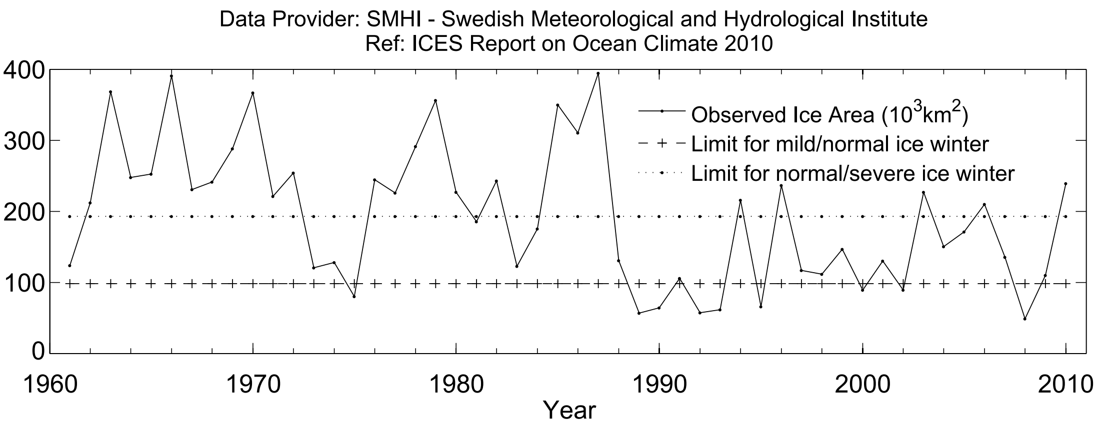


__Figure 62.__
Area 9b – Skagerrak, Kattegat, and the Baltic. Salinity at Station SR5 in the Bothnian Sea (data to 2008; upper panel) and ice extent in the Baltic starting from 1961 (lower panel).





4.14 Area 10 – Norwegian Sea

THE NORWEGIAN SEA IS CHARACTERIZED BY WARM ATLANTIC WATER ON THE EASTERN SIDE AND COLD ARCTIC WATER ON THE WESTERN SIDE, SEPARATED BY THE ARCTIC FRONT. ATLANTIC WATER ENTERS THE NORWEGIAN SEA THROUGH THE FAROE–SHETLAND CHANNEL AND BETWEEN THE FAROES AND ICELAND VIA THE FAROE FRONT. A SMALLER BRANCH, THE NORTH ICELANDIC IRMINGER CURRENT, ENTERS THE NORDIC SEAS ON THE WESTERN SIDE OF ICELAND. ATLANTIC WATER FLOWS NORTH AS THE NORWEGIAN ATLANTIC CURRENT, WHICH SPLITS WHEN IT REACHES NORTHERN NORWAY; SOME ENTERS THE BARENTS SEA, WHEREAS THE REST CONTINUES NORTH INTO THE ARCTIC OCEAN AS THE WEST SPITSBERGEN CURRENT.

Three sections from south to north in the eastern Norwegian Sea demonstrate the development of temperature and salinity in the core of the Atlantic Water (AW): Svinøy, Gimsøy, and Sørkapp. In general, there has been an increase in temperature and salinity in all three sections from the mid-1990s to the present. In all three sections, temperature and salinity were above the long-term means in 2010. In 2010, the annual temperature averages were 0.4°, and 0.2°, and 0.2°C above the long-term mean in the Svinøy, Gimsøy, and Sørkapp sections, respectively. In 2010, salinity values were 0.09, 0.07, and 0.04 above the long-term means for the time-series in the Svinøy, Gimsøy, and Sørkapp sections, respectively. The high salinity values reflect more saline AW in the Faroe–Shetland Channel.

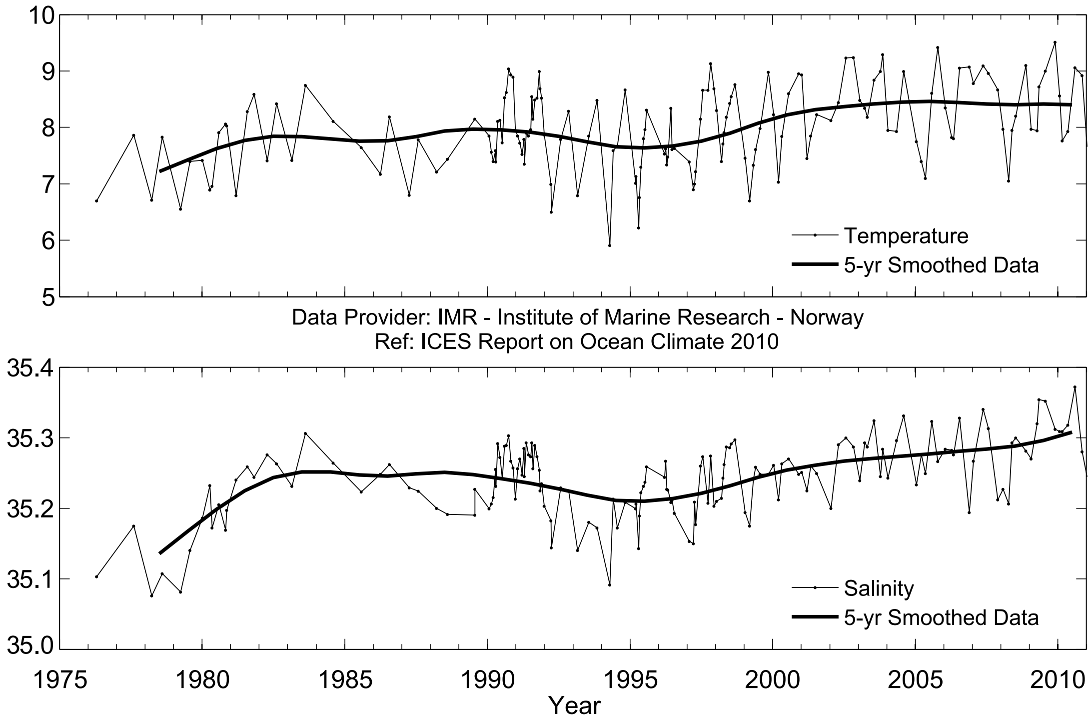


Figure 63. Area 10 – Norwegian Sea. Average temperature (upper panel) and salinity (lower panel) above the slope at Svinøy Section (63°N).

ABOVE-AVERAGE TEMPERATURE AND SALINITY IN THE NORWEGIAN SEA IN 2010.

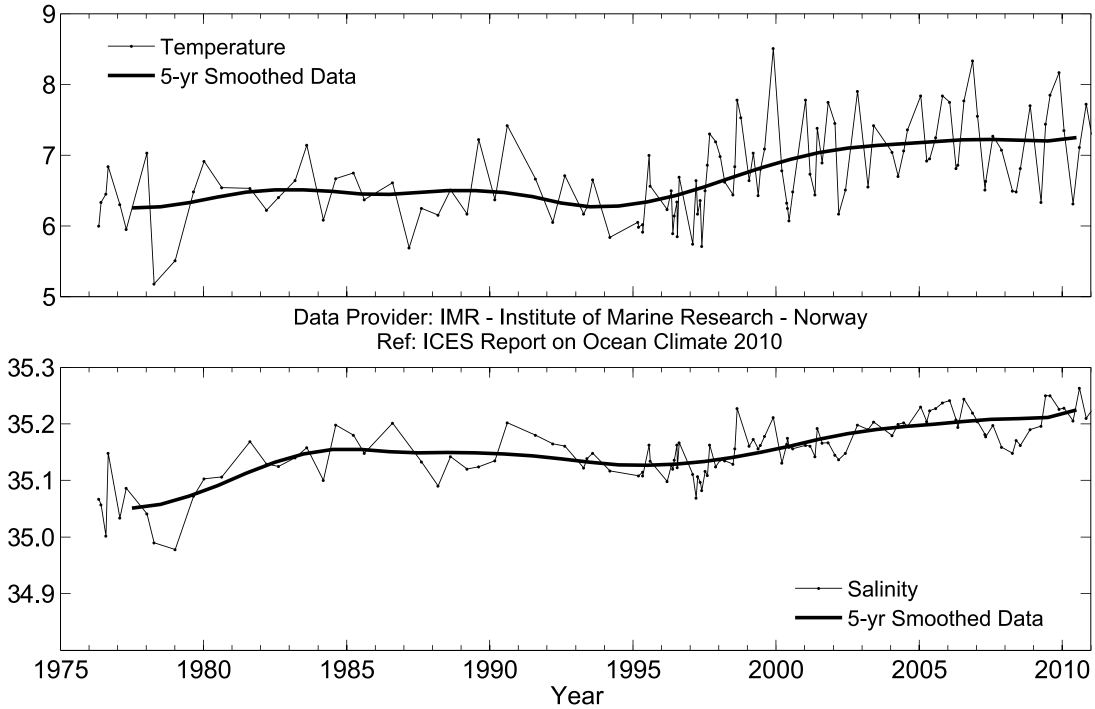


Figure 64.
Area 10 – Norwegian Sea. Average temperature (upper panel) and salinity (lower panel) above the slope at Gimsøy Section (69°N).

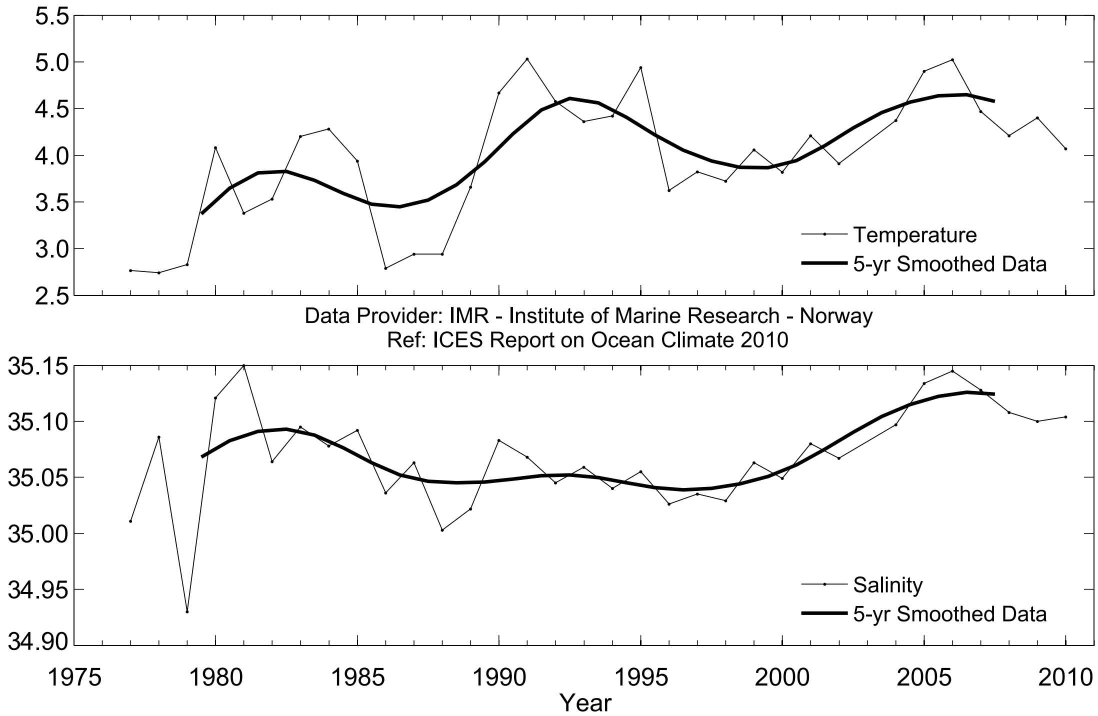


Figure 65.
Area 10 – Norwegian Sea. Average temperature (upper panel) and salinity (lower panel) above the slope at Sørkapp Section (76°N).

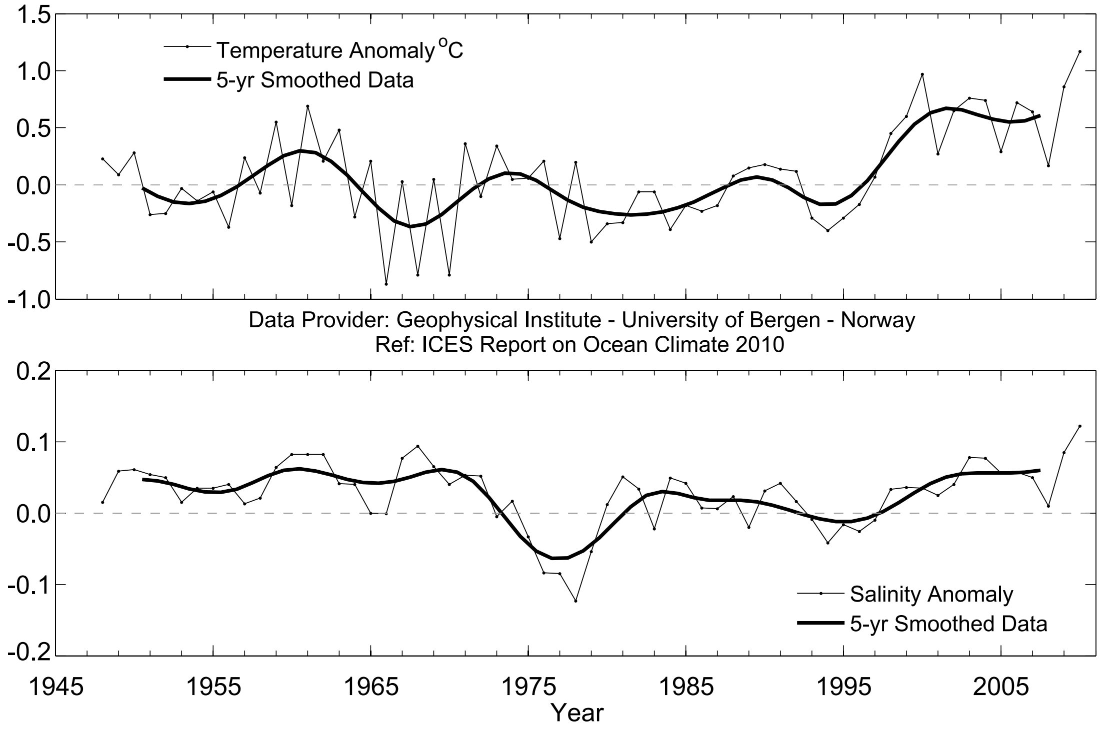


Figure 66.
Area 10 – Norwegian Sea. Temperature anomaly (upper panel) and salinity anomaly (lower panel) at 50 m at Ocean Weather Station "M" (66°N 2°E).

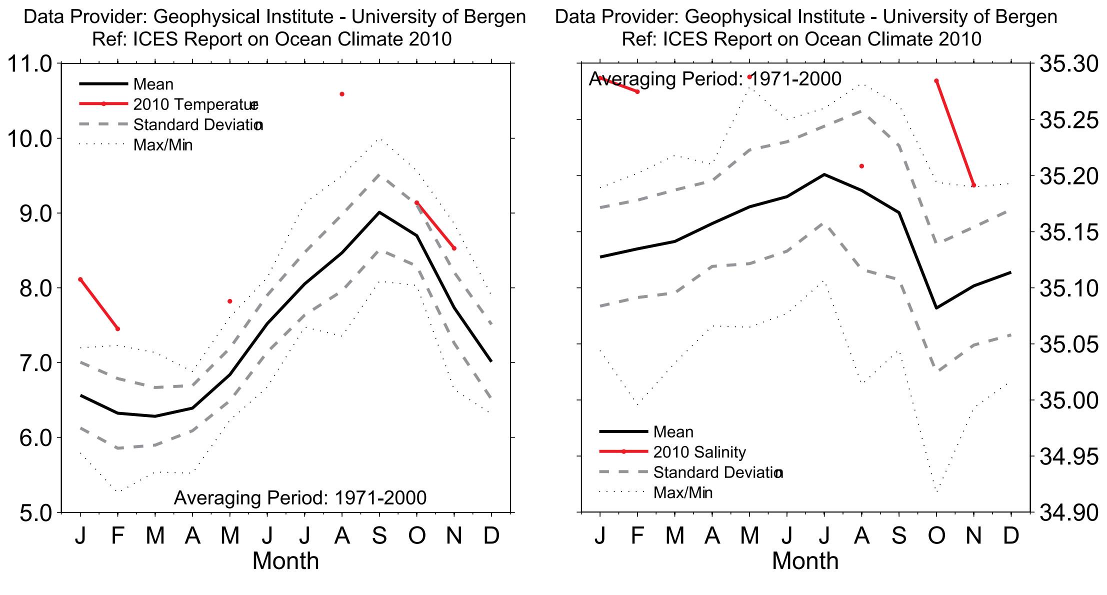


Figure 67.
Norwegian Sea. 2010 monthly temperature (left panel) and salinity (right panel) at 50 m at Ocean Weather Station "M" (66°N 2°E).

4.15 Area 11 – Barents Sea

THE BARENTS SEA IS A SHELF SEA, RECEIVING AN INFLOW OF WARM ATLANTIC WATER FROM THE WEST. THE INFLOW EXHIBITS CONSIDERABLE SEASONAL AND INTERANNUAL FLUCTUATIONS IN VOLUME AND WATER-MASS PROPERTIES, PARTICULARLY IN HEAT CONTENT AND, CONSEQUENTLY, ICE COVERAGE.

In 1996 and 1997, after a period with high temperatures in the first half of the 1990s, temperatures in the Barents Sea dropped to slightly below the long-term average. From March 1998, the temperature in the western Barents Sea increased to just above the average, whereas the temperature in the eastern part remained below the average during 1998. From the beginning of 1999, there was a rapid temperature increase in the western Barents Sea that also spread to the eastern part. Since then, the temperature has remained above average.

The temperature of Atlantic Water in the Barents Sea throughout 2010 was 0.2–1.3ºC higher than average, depending on time and place. The temperature anomalies gradually decreased, whereas the salinity anomalies increased during 2010. In the Kola Section, the salinity anomalies changed from negative to positive values during the first three months of the year. The largest salinity anomalies (0.1) were observed in the coastal waters in December. In the Kola Section (0-200 m), the 2010 annual mean temperature was ca. 0.8°C higher than normal. This is typical of an anomalously warm year and closely resembles the situation in 2009. The annual mean salinity for 2010 was higher than both the average and that of 2009.

In August–September 2010, the surface waters in most of the Barents Sea, especially the eastern part, were colder than normal. However, the waters of the upper 200 m layer were still warmer than normal. The bottom temperatures were 0.1–0.6°C higher than normal, but 0.2–0.3°C lower than in 2009 for most of the sea in August–September 2010. In 2010, the volume of cold bottom waters increased in the northern Barents Sea compared with 2009. Throughout most of 2010, the ice coverage of the Barents Sea was lower than the long-term average. Compared with 2009, it was lower in summer 2010 and higher or close to that in the remainder of 2010.

The volume flux into the Barents Sea varies over periods of several years and was significantly lower during 1997–2002 than in 2003–2006. The year 2006 was special, as the volume flux had both a maximum (in winter 2006/2007) and a minimum (in autumn 2006). Since then, the inflow has been low, particularly during spring and summer. The inflow in 2010 was similar to 2007–2009: moderate during winter followed by a strong decrease in spring. In spring 2010, the flux was almost 0.5 Sv below average. There are no observations for autumn 2010. There is no significant trend in the observed volume flux from 1997 to 2010.

The water temperature in the Barents Sea in 2011 is expected to decrease from a value typical of anomalously warm years to a value typical of warm years and, on average, will probably be 0.2°C lower than in 2010.

ICE COVERAGE OF THE BARENTS SEA WAS LOWER THAN THE LONG-TERM AVERAGE.

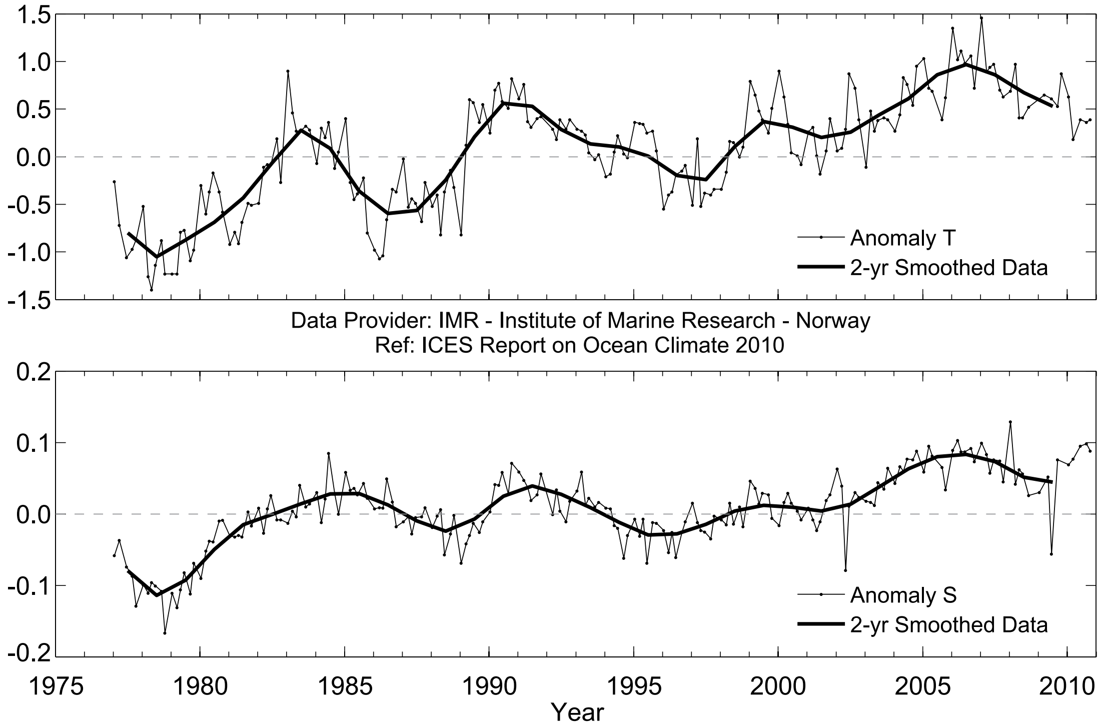


Figure 68.
Area 11 – Barents Sea. Temperature anomaly (upper panel) and salinity anomaly (lower panel) in the Fugløya–Bear Island Section.

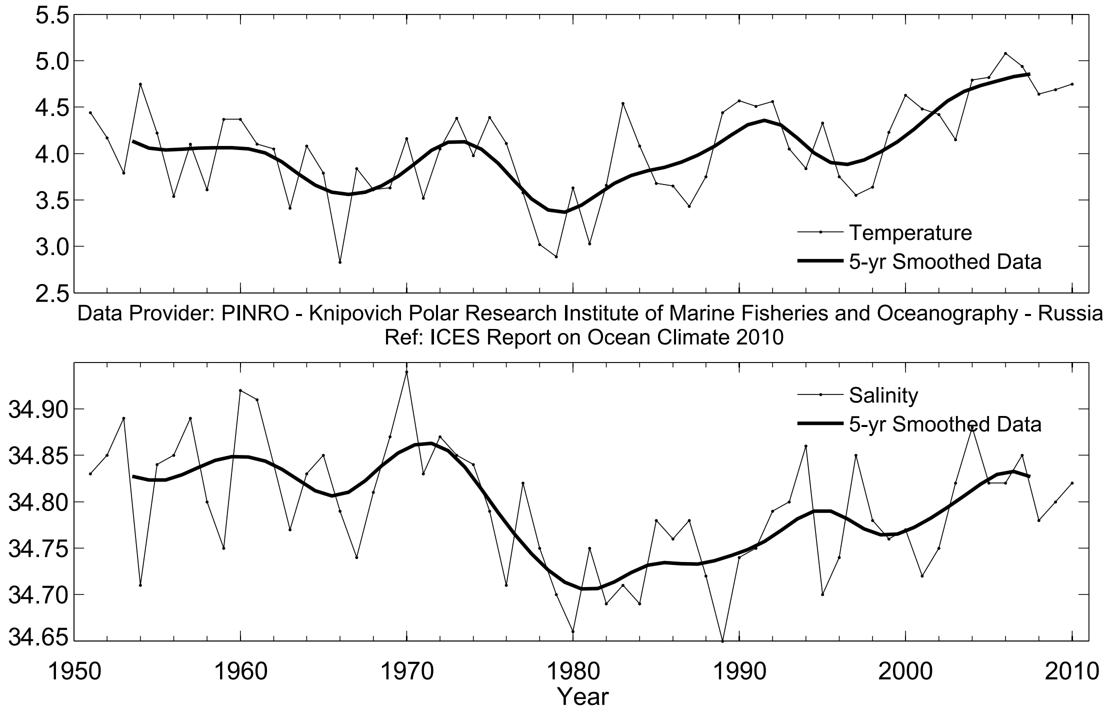


Figure 69.
Area 11 – Barents Sea. Temperature (upper panel) and salinity (lower panel) in the Kola Section (0–200 m).

4.16 Area 12 – Greenland Sea and Fram Strait

FRAM STRAIT IS THE NORTHERN BORDER OF THE NORDIC SEAS. IT IS THE DEEPEST PASSAGE CONNECTING THE ARCTIC TO THE REST OF THE WORLD OCEAN AND ONE OF THE MAIN ROUTES WHEREBY ATLANTIC WATER (AW) ENTERS THE ARCTIC (THE OTHER IS THE BARENTS SEA). THE AW IS CARRIED NORTHWARDS BY THE WEST SPITSBERGEN CURRENT, AND VOLUME AND HEAT FLUXES EXHIBIT STRONG SEASONAL AND INTERANNUAL VARIATIONS. A SIGNIFICANT PART OF THE AW ALSO RECIRCULATES WITHIN FRAM STRAIT AND RETURNS SOUTHWARDS (RETURN ATLANTIC WATER). POLAR WATER FROM THE ARCTIC OCEAN FLOWS SOUTH IN THE EAST GREENLAND CURRENT AND AFFECTS WATER MASSES IN THE NORDIC SEAS.

In 2010, the temperature of Atlantic Water (AW) at the eastern rim of the Greenland Sea (along the 75°N section, between 10° and 13°E), was similar to that observed in 2008 (no data for 2009) and close to the long-term mean. A significant increase in salinity was observed compared with 2008 and, since 2004, the salinity of AW has remained higher than its long-term average. At the western rim of the Greenland Sea, the temperature of Return Atlantic Water (RAW) was slightly lower than that observed in 2009, whereas salinity remained similar to the 2009 value. Both values were close to their long-term means. Temperature and salinity in the upper layer of the central Greenland Basin, within the Greenland Gyre, were modified by the advection of AW and winter convection. The interface with enhanced temperature and salinity gradients has steadily descended (by more than 1000 m) since the beginning of measurements in 1993. After winter 2007/2008, a two-layer structure resulted from a mixed-layer type convection that supplied both salt and heat into the intermediate layers. In winter 2008/2009, almost half of the Greenland Sea had been shielded from convection because of the unusual western location of the Arctic Front (boundary between Atlantic and Greenland Sea waters).

In summer 2009, an unusual hydrographic situation was observed in the Greenland Gyre. In contrast to the usual relatively homogeneous pool, mixed by winter convection, a bipolar characteristic, of water masses with saline waters in the western part of the gyre and fresher waters in the eastern part, was found along the 75°N section. This made it difficult to define the convection depth and to compose a reliable mean profile for the gyre centre. Without a 2009 mean profile, it was difficult to compare the average profiles in 2009 and 2010, and impossible to provide an unambiguous estimate of the convection depth in winter 2009/2010.

In recent years, the hydrographic situation in the Greenland Sea has been characterized by the increasing and overwhelming influence of AW inflow. This trend continued in the western half of the Greenland Gyre during 2009, but was interrupted by a freshwater event in the eastern half. The mean salinity in the central Greenland Sea in summer 2010 (not shown) suggests that the high-salinity intrusion into the gyre centre had already surpassed its maximum. There was a tendency towards fresher waters in the gyre centre, but the salinity was still higher than before 2004.

In the southern Fram Strait, a record-high summer temperature for AW was observed in 2006, after which both temperature and salinity decreased rapidly in 2007 and 2008, before increasing again in summer 2009. In 2010, both temperature and salinity anomalies were still above their 15-year means, although salinity was higher and temperature slightly lower than in 2009. Mean temperature at 200 dbar at the standard section (76.50°N; averaged between 9° and 12°E) was 3.44°C, 0.25°C more than the 1996–2010 mean. Salinity reached 35.10, ca. 0.039 more than the 1996–2010 mean. Both temperature and salinity trends were positive.

IN 2010, THE TEMPERATURE OF THE ATLANTIC WATER IN THE GREENLAND SEA AND FRAM STRAIT WAS CLOSE TO THE MEAN VALUE, WHEREAS A FURTHER INCREASE IN SALINITY WAS OBSERVED.

In the northern Fram Strait, at the standard section along 78.83°N, three characteristic areas can be distinguished in relation to the main flows: the West Spitsbergen Current (WSC) between the shelf edge and 5°E, the Return Atlantic Current (RAC) between 3°W and 5°E, and the Polar Water in the East Greenland Current (EGC) between 3°W and the Greenland Shelf. After their record-high maxima in 2006, the mean temperature and salinity in the WSC decreased, reaching their lowest decadal values in 2008. In 2009, both temperature and salinity recovered from their minima, returning to (temperature) or exceeding (salinity) their long-term means. In summer 2010, temperatures in the eastern and central Fram Strait (WSC and RAC) remained close to values from the previous year, whereas a further increase of salinity was observed in both areas. Potential density of the AW entering the Arctic Ocean within the WSC increased in 2010, mostly owing to high salinity, and was the second highest in the last decade, after a decadal maximum in 2008.

Strongest positive salinity anomalies were observed in the recirculation area, particularly in the ECG. Mean salinity reached a record high in the RAC and was among the three highest values ever recorded in the ECG (excluding 2007, which was not representative because of the shorter section omitting the freshwater on the East Greenland shelf slope). In the RAC, the highest salinity was found in the upper layer of 100–150 m, whereas, in the EGC, the strongest anomaly was observed in the surface and subsurface freshwater layers to a depth of ca. 200 m, where salinity was significantly higher than 2008 (not measured in 2009) and greatly exceeded the long-term average. The thickness of the freshwater layer (salinity >34) in the EGC in 2010 was less than half of that observed in 2008.

Water with high salinities (<34.9) was found as far as 7°W on the upper shelf slope east of Greenland, and at depths as shallow as 200 m. In the EGC, the temperature of the upper freshwater layer was close to average, whereas a weakly positive temperature anomaly was found in the AW derivatives below. On average, temperature in the upper 50–500 m of the EGC was significantly higher than in 2008 and slightly exceeded its long-term average.

An anomalous atmospheric circulation in winter 2009/2010, characterized by the absence of a winter low in the Nordic seas and an extremely negative NAO index, resulted in very weak inflow of AW in the West Spitsbergen Current during winter (except for one stronger event in December). However, during the following spring and summer, the volume transport was higher than average (the summer minimum in the volume transport was not observed). As a result, the 2009–2010 winter-centred annual mean of the net volume transport in the WSC was only slightly lower than in the previous year (5.6 Sv compared with 6.2 Sv in 2008–2009) and lower than the long-term average of 6.6 Sv for the period 1997–2010.

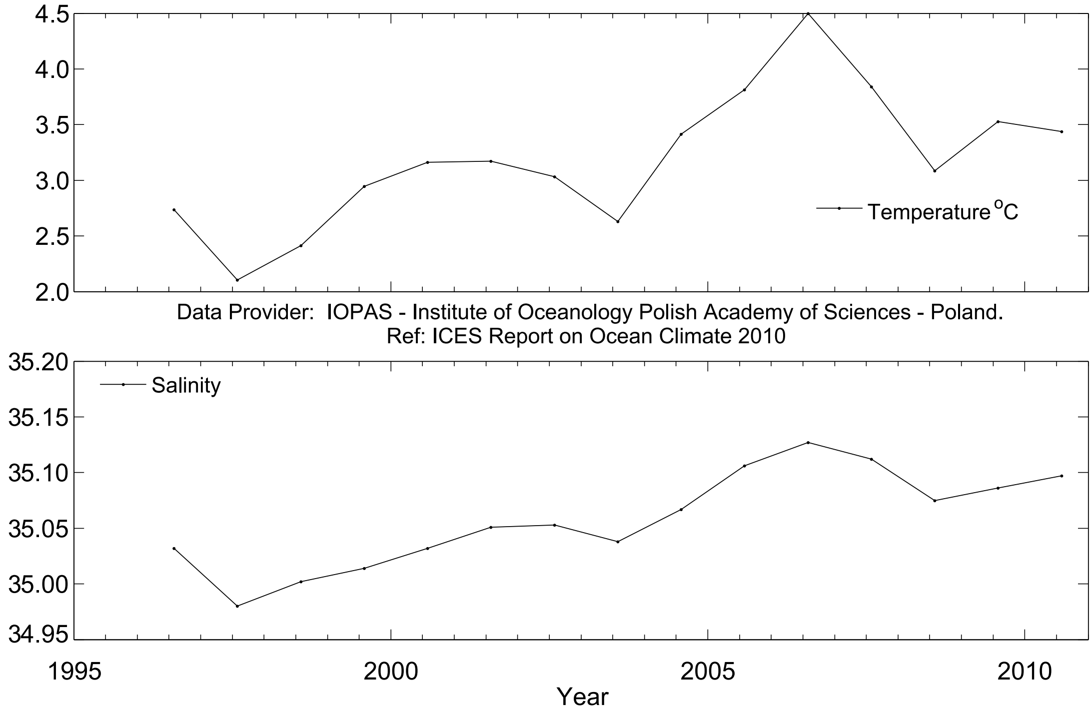


Figure 70.
Area 12 – Greenland Sea and Fram Strait. Temperature (upper panel) and salinity (lower panel) at 200 m in the Spitsbergen Section (76.50°N).

Figure 71.
Area 12 – Greenland Sea and Fram Strait. Temperature anomaly (upper panel) and salinity (lower panel) anomaly of Atlantic Water (AW) and Return Atlantic Water (RAW) in the Greenland Sea Section at 75°N. AW properties are 50–150 m averages at 10–13°E. The RAW is characterized by temperature and salinity maxima below 50 m averaged over three stations west of 11.5°W.

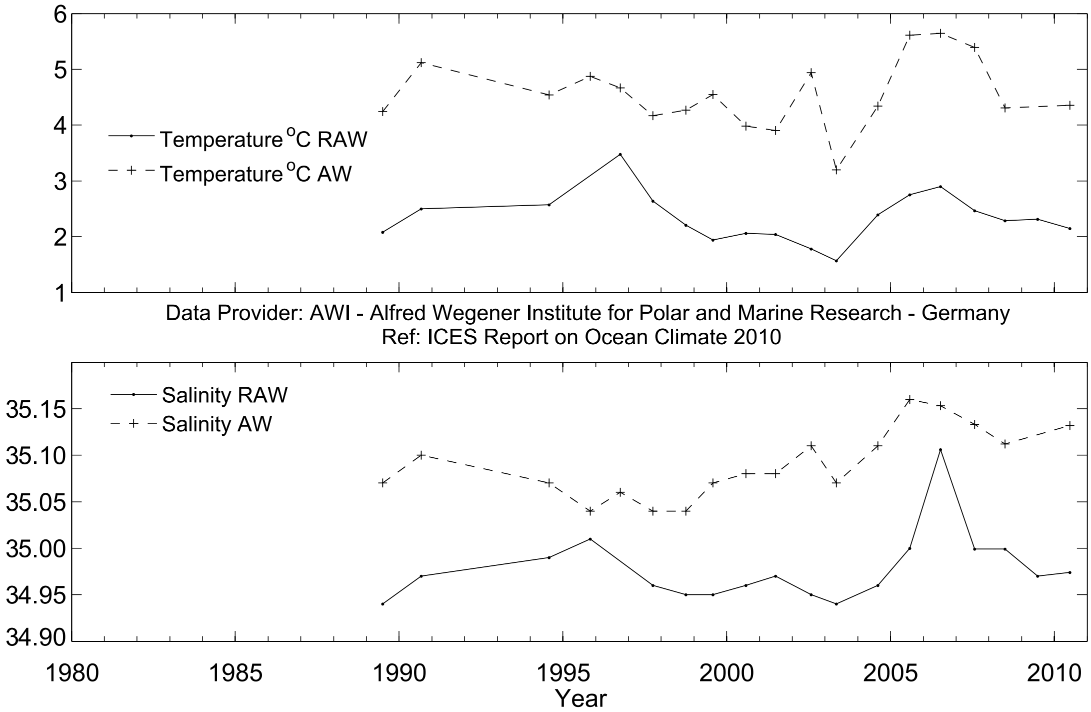


Figure 72.
Area 12 – Greenland Sea and Fram Strait. Temperature anomaly (upper panel) and salinity (lower panel) anomaly in Fram Strait (78.83°N) at 50–500 m: in the West Spitsbergen Current (WSC; between the shelf edge and 5°E), in the Return Atlantic Current (RAC; between 3°W and 5°E), and in the Polar Water in the East Greenland Current (EGC; between 3°W and the Greenland Shelf).

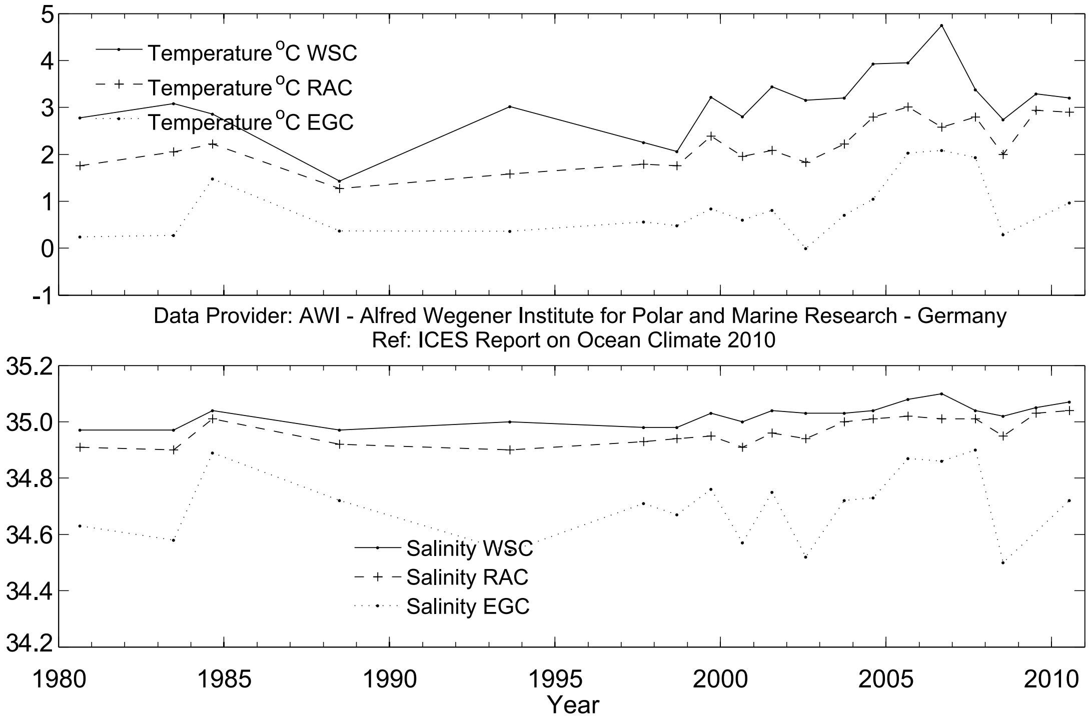


Image courtesy of H. Klein, BSH Hamburg, Germany.

5. DETAILED AREA DESCRIPTIONS, PART II: THE DEEP OCEAN

5.1 Introduction

In this section, we focus on the deeper waters of the Nordic seas and the North Atlantic, typically below 1000 m. The general circulation scheme and dominant water masses are given in Figure 73.

At the northern boundary of our region of interest, the cold and dense outflow from the Arctic Ocean enters Fram Strait and reaches the Greenland Sea. The outflow is a mixture of Eurasian Basin and Canadian Basin Deep Waters and Upper Polar Deep Water (UPDW). The Eurasian Deep Water feeds the densest water of all Nordic seas: the Greenland Sea Bottom Water. The Canadian Basin Deep Water and UPDW supply the Arctic Intermediate Water in the Greenland Sea, and the UPDW also includes products of the winter convection.

The deep southward outflow from the North Atlantic in the Deep Western Boundary Current is fed by the cold and dense overflow waters. The deepest and densest is the Denmark Strait Overflow Water. This water mass originates in the Arctic Intermediate Water produced in the Greenland and Iceland seas by winter convection and mixing with surrounding water masses. The Denmark Strait Overflow Water sinks to the bottom as it passes over the Denmark Strait sill, vigorously entraining ambient water. Downstream, it is overlain by an intermediate water mass, the Labrador Sea Water, formed by deep winter convection in the Labrador Sea. The middle layer of the deep, cold-water export in the Deep Western Boundary Current is supplied by the Iceland–Scotland Overflow Water, originating in water masses formed in the Norwegian Sea (Arctic Intermediate Water and North Atlantic Deep Water). Passing through the Icelandic Basin, the Iceland–Scotland Overflow Water also entrains upper ocean water and Labrador Sea Water. The deep Antarctic Bottom Water enters the North Atlantic on the western side and some of the Lower Deep Water accompanies the inflow of Mediterranean Water on the eastern side.

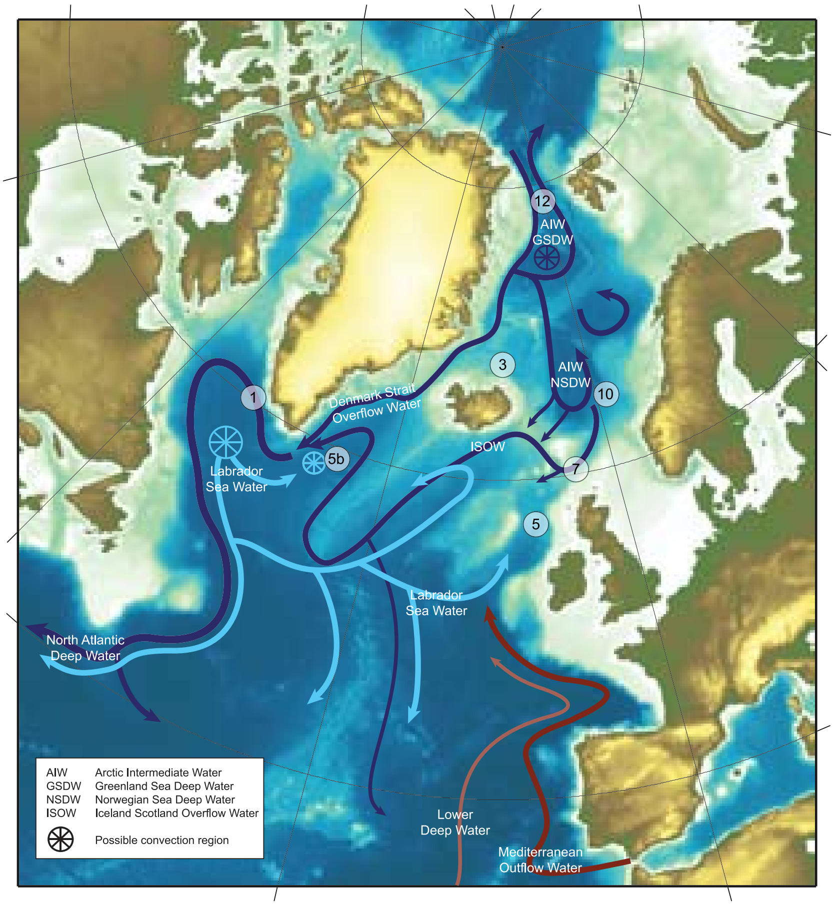


Figure 73.
Schematic circulation of the intermediate to deep waters in the Nordic seas and North Atlantic.

5.2 Nordic seas deep waters

The deep waters of the Greenland, Iceland, and Norwegian seas are all warming. The longest time-series (the Norwegian Sea, Area 10, no data for 2010) reveals warming from the mid-1980s; however, a slight decrease in temperature occurred in 2007. The continuous warming has been observed in the Greenland Sea deep layer at 3000 m (Area 12), and the temperature increase between 2009 and 2010 was slightly lower (0.01°C) than the increase over the past five years (0.014°C). Warming in the Greenland Sea was accompanied by a year-to-year increase in salinity of 0.001. In the Iceland Sea, an increase in temperature in the depth range 1500–1800 m has been observed since the beginning of the time-series (early 1990s), and the temperature in 2010 continued to rise slowly. The long-term warming rates for the last decade are 0.134°C (Greenland Sea), 0.06°C (Norwegian Sea), and 0.064°C (Iceland Sea). The source of the warming is the deep outflow from the Arctic Ocean, a south-flowing current of the Eurasian and Canadian Basin Deep Waters and the upper Polar Deep Water found on the western side of Fram Strait at ca. 2000 m depth. The Greenland Sea Deep Water (GSDW) is warming fastest owing to its direct contact with this Arctic outflow, whereas the Iceland and Norwegian seas are warming more slowly because they are products of the mixing of their own ambient waters with GSDW and Arctic outflow water.

The doming structure in the Greenland Gyre is being replaced by a two-layered water mass arrangement, after a cessation of deep convection. Since the beginning of measurements in 1993, the winter convection depth has varied between 700 and 1600 m, and has only been significantly deeper in small-scale convective eddies. In winter 2007/2008, the maximum convection depth was estimated to be 1700 m, deeper than the previous year (1200 m) and similar to the maxima observed during 2001/2002 and 2002/2003. The import of warm and saline Atlantic Water (AW) to the Greenland Sea is currently not balanced by an import of cool and fresh Polar Waters from the north. The AW, which dominates changes in the upper ocean, took over the role of former ice production as a source of salt and densification in the context of winter convection. The input of AW tends to prevent ice formation and to vertically homogenize the waters ventilated by convective processes. The GSDW formerly included a small admixture of surface freshwater through the convective process and, therefore, had a lower salinity than the Arctic outflow waters. The observed increase in GSDW salinity may be the result of an adjustment to the Arctic outflow in the continued absence of deep convection and an increased presence of AW in the upper layer.

In summer 2009, in the Greenland Gyre, the usual relatively homogenous pool, mixed by previous winter convection, was replaced by a bipolar distribution of water masses with higher salinity in the western part of the gyre and fresher waters in its eastern part. This made it difficult to compose a reliable mean profile for the gyre centre and, consequently, because of the lack of a 2009 mean profile for comparison with the 2010 mean profile, it was not possible to provide an unambiguous estimate of the convection depth in winter 2009/2010.

It is unclear whether there has been any corresponding salinity trend in either the Norwegian or the Iceland Sea Deep Waters in recent decades. After some decrease in the early 1990s, salinity in Norwegian Sea deep basins has remained relatively stable for the past decade. In the Iceland Sea, salinity in the deep layer has been decreasing slightly since 2009, after being stable for nearly a decade.

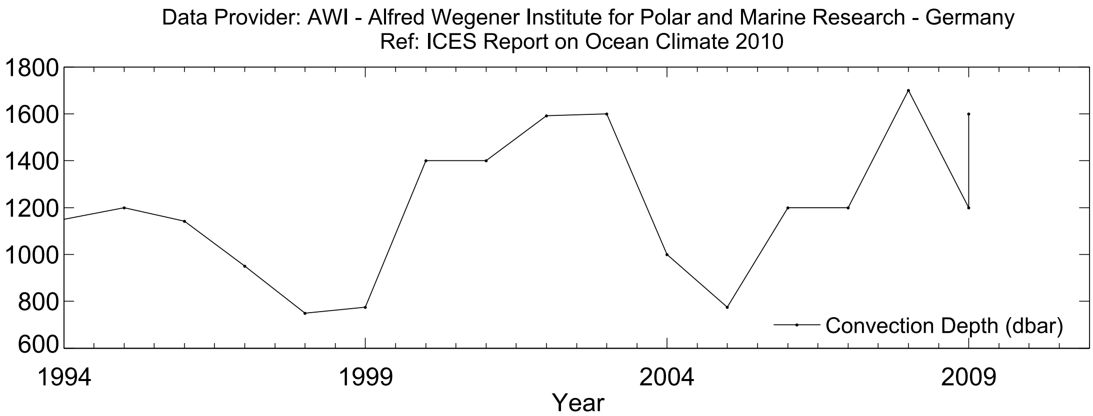


Figure 74.
Area 12 – Greenland Sea and Fram Strait. Winter convection depths in the Greenland Sea Section at 75°N (not updated for winter 2009/2010).

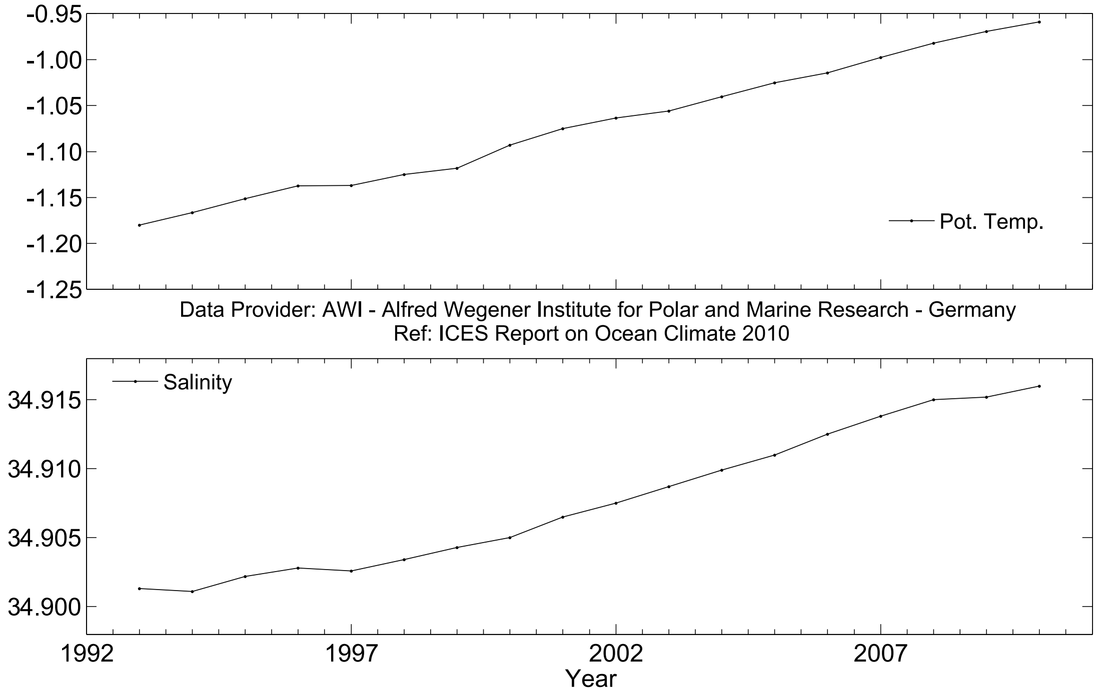


Figure 75.
Area 12 – Greenland Sea and Fram Strait. Temperature (upper panel) and salinity (lower panel) at 3000 m in the Greenland Sea Section at 75°N.

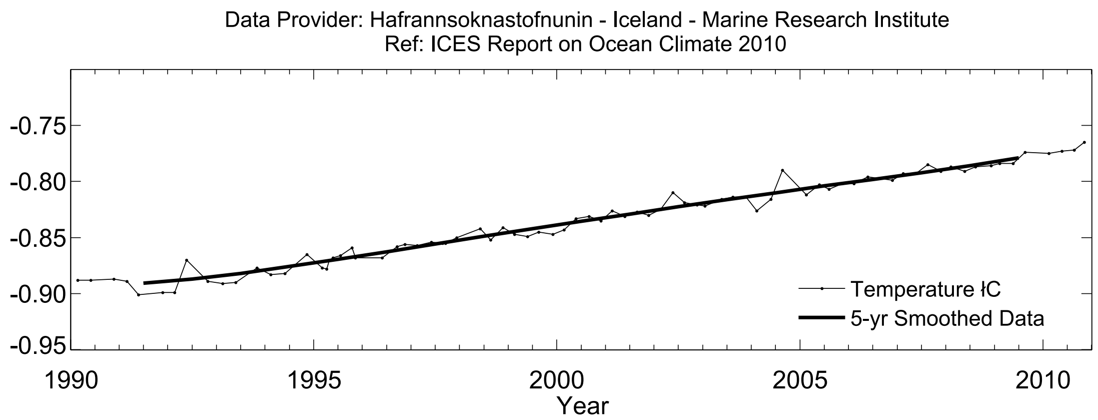


Figure 76.
Area 3 – Icelandic waters. Temperature at 1500–1800 m in the Iceland Sea (68°N 12.67°W).

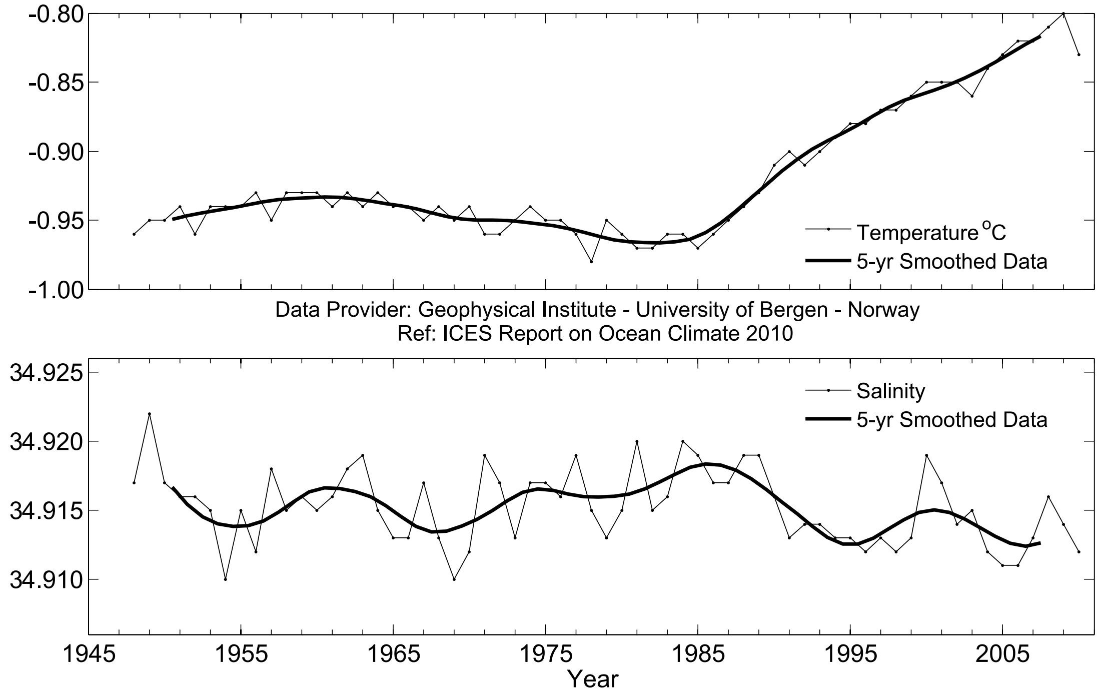


Figure 77.
Area 10 – Norwegian Sea. Temperature (upper panel) and salinity (lower panel) at 2000 m at Ocean Weather Station "M" (66°N 2°E).

5.3 North Atlantic deep waters

In the deep layers of the Faroe–Shetland Channel (Area 7), the properties at 800 m are the same as those of Norwegian Sea Deep Water as it passes through the channel back into the North Atlantic. After a period of decline in the 1990s, temperature has increased since 2000, but still remains lower than the highest temperatures observed in the 1950s, 1960s, and early 1980s. The relatively stable salinity in the first period of measurements (1950 to mid-1970s) was followed by a slow decline through the subsequent 15 years; since 1992, it has stabilized again. In 2010, both temperature and salinity remained close to their mean values for the past decade.

The salinity and potential temperature of the Denmark Strait Overflow Water (DSOW) near Cape Farewell exhibited considerable well-correlated interannual variations between 1991 and 2007 (correlation = 0.7). However, since 2007, the changes in temperature and salinity of the DSOW broke this rule. Temperature decreased and salinity increased, leading to the highest potential density of DSOW since the time-series started in 1991. Subsequently, temperature increased and salinity decreased towards the end of 2009. In 2010, both parameters co-varied again: temperature increased by 0.2°C and salinity by 0.1 compared with the previous year. The long-term standard deviations in temperature and salinity are 0.14°C and 0.014, respectively. No significant long-term trend since 1990 is visible in these parameters. Measurements with moored instrumentation have demonstrated that temperature and density mainly vary at an annual time-scale, possibly forced by wind-driven processes near Denmark Strait.

In the North Atlantic Deep Water (NADW), monitored at Cape Desolation Station 3 (at 2000 m), which represents the West Greenland and Deep Western Boundary currents, an increase in temperature and salinity was observed between 1984 and 1989, followed by a cooling and freshening trend that continued until the late 1990s. Since 1997, an increase in temperature (~0.3°C decade^{-1}) and, since 1998, an increase in salinity (~0.05 decade^{-1}), have been observed again. The positive trends were observed until 2007, after which the temperature of the NADW has been decreasing and salinity has remained relatively stable. This decrease in the NADW temperature continued in 2010, and the temperature returned to its long-term mean value. The salinity underwent only a tiny decrease since 2008 and was still above normal.

THE DENMARK STRAIT OVERFLOW WATER WAS WARMER AND MORE SALINE IN 2010, WHEREAS PROPERTIES OF THE NORTH ATLANTIC AND NORWEGIAN SEA DEEP WATERS REMAINED CLOSE TO THEIR LONG-TERM MEANS.

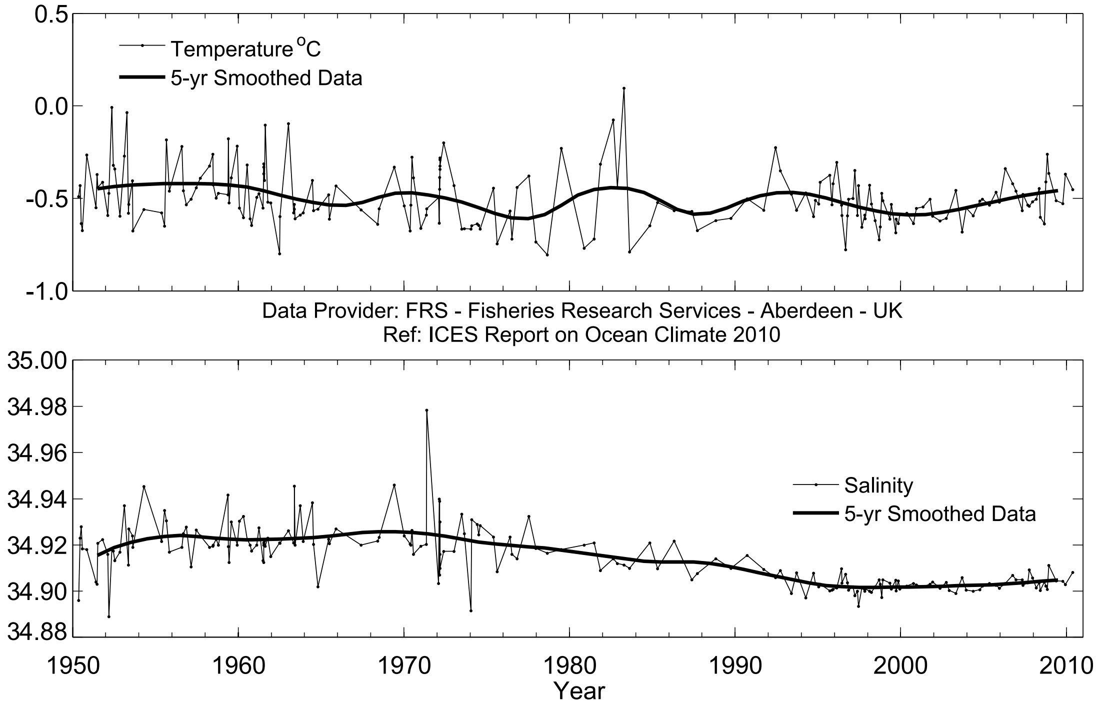


Figure 78.
Area 7 – Faroe–Shetland Channel. Temperature (upper panel) and salinity (lower panel) at 800 m.

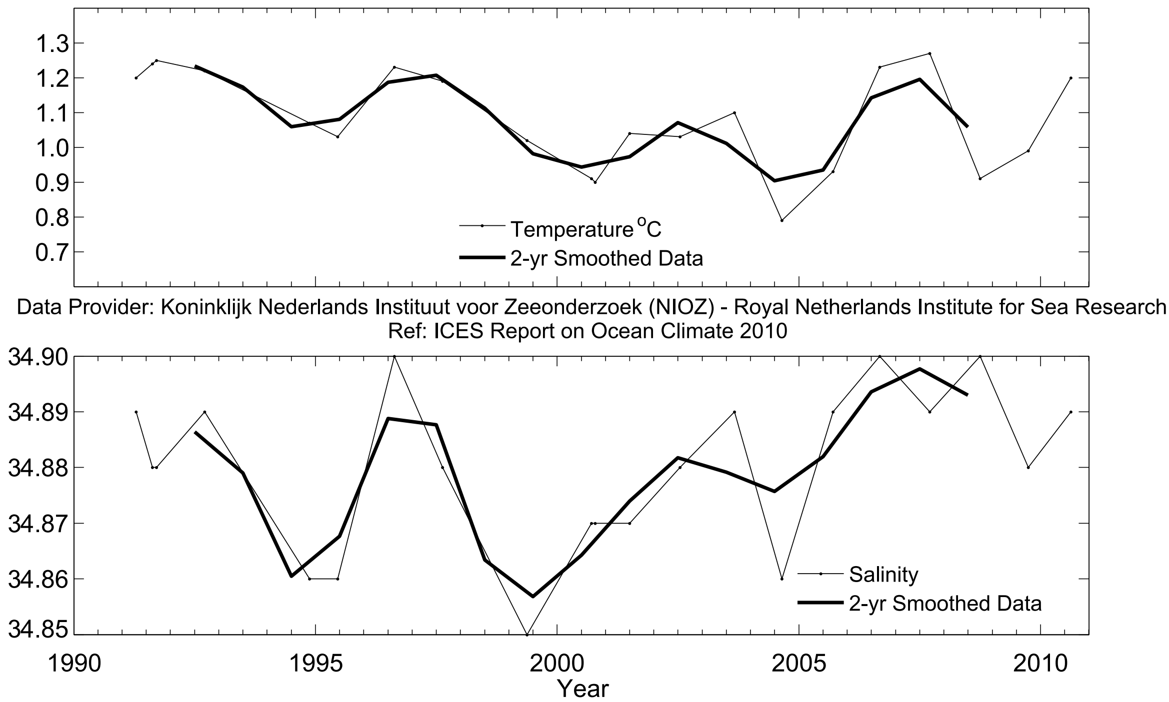


Figure 79.
Area 5b – Irminger Sea. Temperature (upper panel) and salinity (lower panel) in Denmark Strait Overflow Water on the East Greenland Slope.

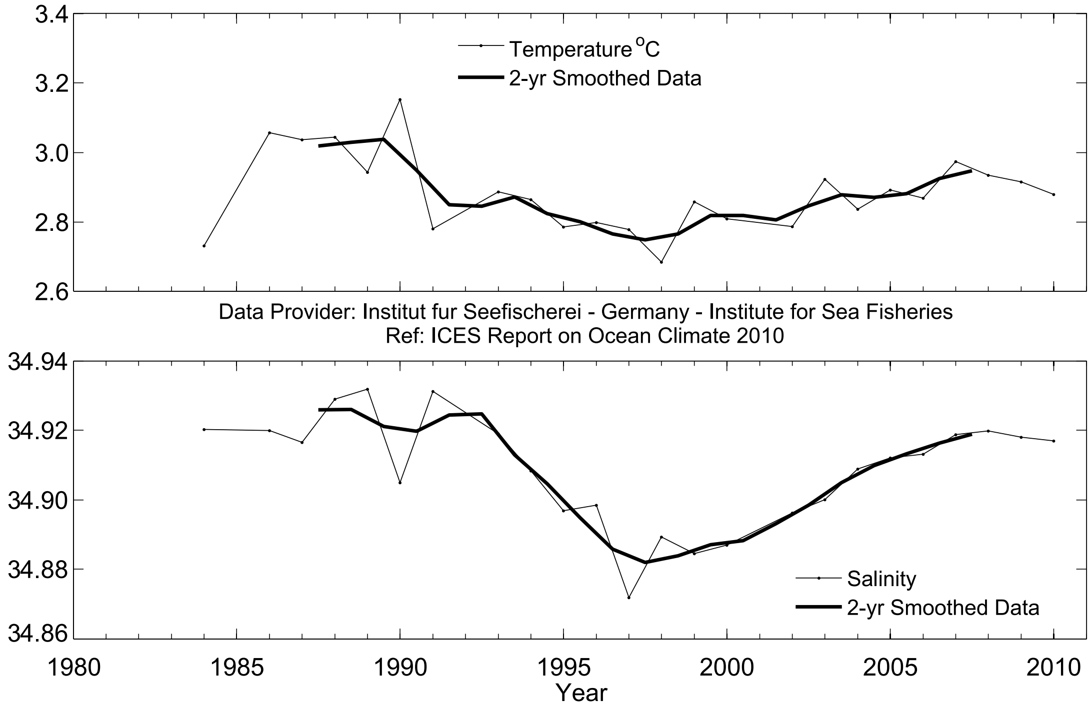


Figure 80.
Area 1 – West Greenland. Temperature (upper panel) and salinity (lower panel) at 2000 m at Cape Desolation Station 3 in the West Greenland Current.

5.4 North Atlantic intermediate waters

A cold and low-salinity core was observed between 1600 and 2000 m in the central Irminger Sea (Area 5b) during the early 1990s. This was the result of the presence of deep Labrador Sea Water (LSW) formed in the period 1988–1995. Since summer 1996, the temperature and salinity of this LSW core have been increasing as a result of mixing with surrounding water masses. The increases levelled off in 2001–2002, then slowly began to increase again. In 2009, temperature reached a minimum as a result of the temporary presence of a cold LSW core, formed in 2008. In 2010, the highest temperature since measurements began in 1991 was recorded. The salinity of the LSW in 2010 differed little from that of the three previous years.

In the Rockall Trough (Area 5), the LSW is defined by weak stratification minimum salinity, and a potential vorticity of 1700–2000 m. Measurements made in May 2010 indicate that potential temperature and salinity of the potential vorticity minimum remain cooler and fresher than the long-term record. The cooler, fresher LSW that invaded the trough in 1990 remains, and both potential temperature and potential salinity in 2010 were almost unchanged from 2009.

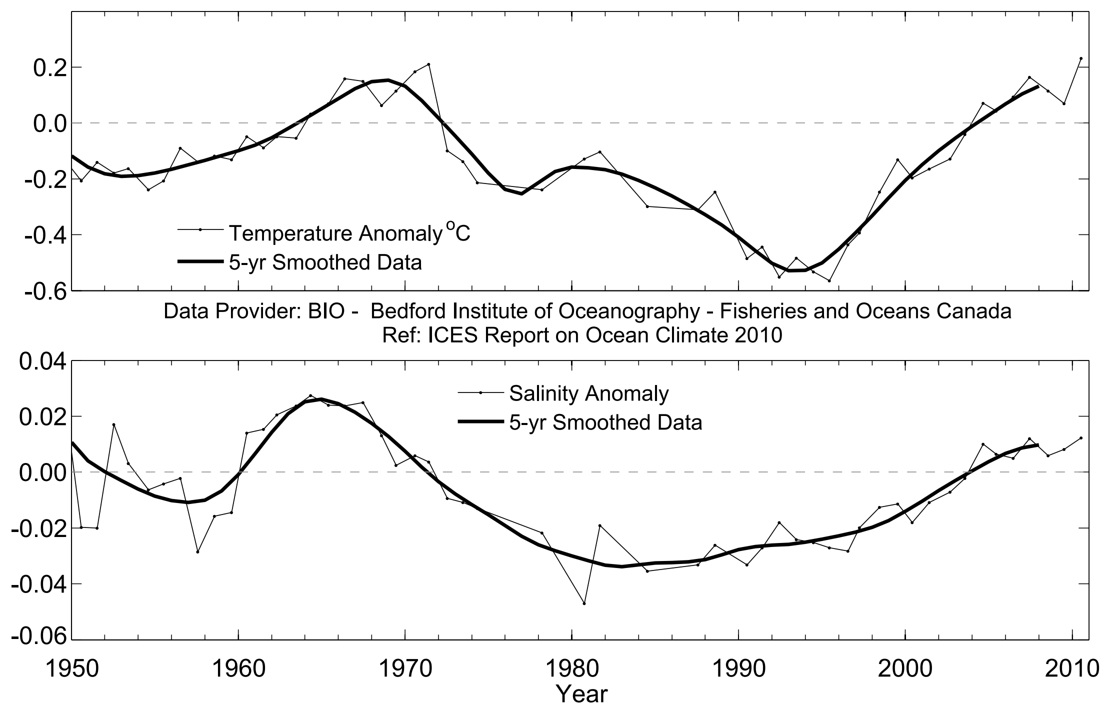


Figure 81.
Area 2b – Labrador Sea. Temperature (upper panel) and salinity (lower panel) of Labrador Sea Water.

Figure 82.
Area 5b – Irminger Sea. Temperature (upper panel) and salinity (lower panel) of Labrador Sea Water (averaged over 1600–2000 m).

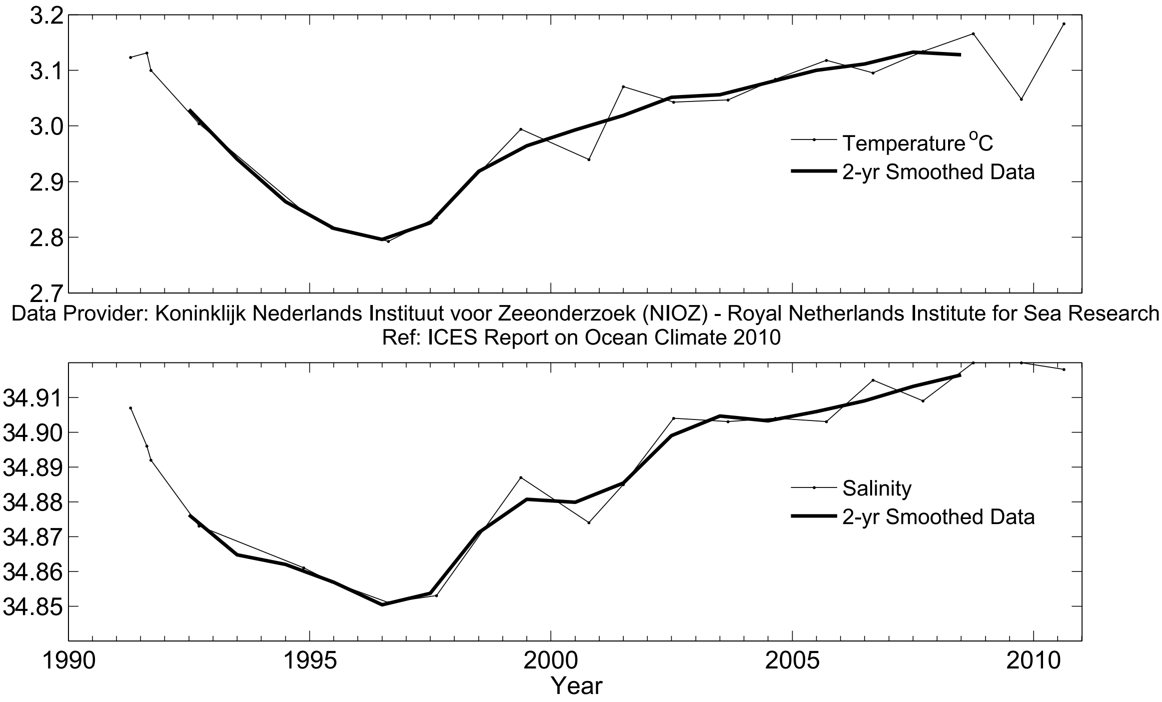
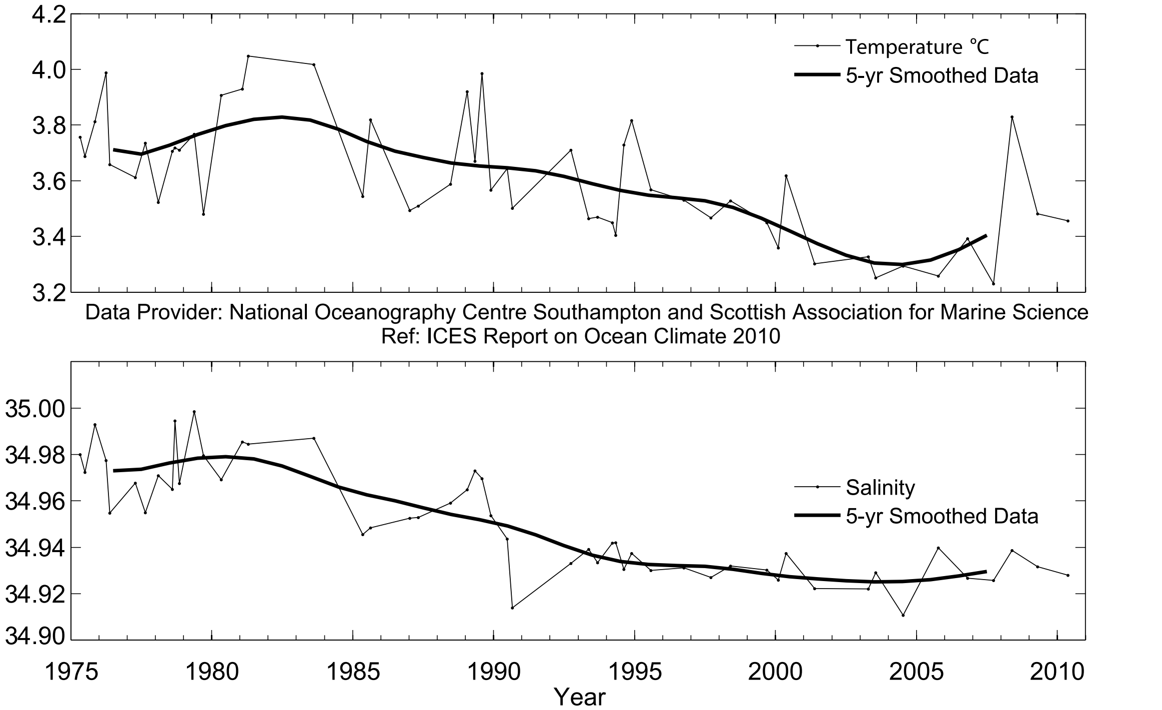


Figure 83.
Area 5 – Rockall Trough. Temperature (upper panel) and salinity (lower panel) of Labrador Sea Water (1800–2000 m).



AFTER A SHORT COLD AND FRESHER SPELL IN 2008–2009, THE IRMINGER SEA RECOVERED IN 2010 TO A WARM AND RELATIVELY SALINE STATE.

CONTACT INFORMATION

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1	West Greenland	14	Nuuk-air temperature	Anna Akimova (ana.akimova@vti.bund.de)	Danish Meteorological Institute, Copenhagen, Denmark, and Seewetteramt, Hamburg, Germany
1	West Greenland	15, 16, 80	Fylla Section and Cape Desolation Section	Anna Akimova (ana.akimova@vti.bund.de)	Institut für Seefischerei (Institute for Sea Fisheries), Germany
2	Northwest Atlantic	17, 18	Sable Island Air Temperature, Cabot Strait Sea Ice, Misaine Bank	Brian Petrie (PetrieB@mar.dfo-mpo.gc.ca)	BIO (Bedford Institute of Oceanography), Fisheries and Oceans, Canada
2	Northwest Atlantic	19	Emerald Bank	Brian Petrie (PetrieB@mar.dfo-mpo.gc.ca)	BIO (Bedford Institute of Oceanography), Fisheries and Oceans, Canada
2	Northwest Atlantic	20, 21	Sea Ice, Cartwright Air Temperature, Station 27 CIL	Eugene Colbourne (colbourn@dfo-mpo.gc.ca)	Northwest Atlantic Fisheries Centre, Canada
2b	Labrador Sea	22, 23, 24, 81	Section AR7W	Igor Yashayaev (Igor.Yashayaev@dfo-mpo.gc.ca)	BIO (Bedford Institute of Oceanography), Fisheries and Oceans Canada
2c	Mid-Atlantic Bight	25, 26, 27, 30	Central MAB and Gulf of Maine	Paula Fratantoni (pfratantoni@whoi.edu)	Woods Hole Oceanographic Institution, USA
2c	Mid-Atlantic Bight	28, 29	Georges Bank	Maureen Taylor (mtaylor@mercury.wh.whoi.edu)	NOAA Fisheries, NEFSC Oceanography Branch, USA
3	Icelandic Waters	31, 32, 33, 34, 35, 76	Air Temperatures, Siglunes Stations 2–4, Selvogsbanki Station 5, Langanes Stations 2–6, Deep Data 1800 m	Hedinn Valdimarsson (hv@hafro.is)	Hafrannsoknastofnunin (Marine Research Institute), Iceland
4	Bay of Biscay	36	San Sebastian Temperature and Air Temperature	Victor Valencia (vvalencia@pas.azti.es)	AZTI, Aquarium of San Sebastian (SOG) and Igeldo Meteorological Observatory (INM), San Sebastian, Spain
4	Bay of Biscay	37, 38	Santander Station 6 (shelf break)	Alicia Lavin (alicia.lavin@st.ieo.es)	Instituto Español de Oceanografía (IEO, Spanish Institute of Oceanography), Spain
4b	NW European Continental Shelf	39, 40	Astan Station	Pascal Morin (Mpmorin@sb-roscoff.fr)	CNRS, Observatoire Oceanologique de Roscoff and IFREMER, France
4b	NW European Continental Shelf	41, 42	Western Channel Observatory, station E1	Tim J. Smyth (tjsm@pml.ac.uk)	Marine Biological Association and Plymouth Marine Laboratory, UK
4b	NW European Continental Shelf	43	Malin Head Weather Station	Glenn Nolan (Glenn.Nolan@marine.ie)	Marine Institute and Met Éireann, Ireland
4b	NW European Continental Shelf	44	M3 Marine Weather Buoy	Sheena Fennel (Sheena.Fennell@marine.ie)	Marine Institute and Met Éireann, Ireland
5	Rockall Trough	45, 83	Ellett Line	Toby Sherwin (toby.sherwin@sams.ac.uk) Jane Read (jfr@noc.soton.ac.uk)	Scottish Association for Marine Science and National Oceanography Centre, Southampton, UK
5b	Irminger Sea	46, 79, 82	Irminger Sea	H. M. van Aken (aken@nioz.nl)	Koninklijk Nederlands Instituut voor Zeeonderzoek (NIOZ, Royal Netherlands Institute for Sea Research), Netherlands
6	Faroe Bank Channel	48, 49, 50	Faroe Bank Channel Faroe Current, coastal stations	Karin Margretha Larsen (KarinL@frs.fo)	Havstovan, Faroe Marine Research Institute, Faroe Islands
7	Faroe Shetland Channel	51, 52, 78	Faroe Shetland Channel	Sarah Hughes (s.hughes@marlab.ac.uk)	FRS (Fisheries Research Services), Aberdeen, UK
8&9	North Sea	53	Modelled North Sea Inflow	Morten Skogen (morten@imr.no)	IMR (Institute of Marine Research), Norway
8&9	North Sea	53	North Sea Utsire A	Solfrid Hjollo (solfrid.hjollo@imr.no)	IMR (Institute of Marine Research), Norway
8&9	North Sea	54	Fair Isle Current Water	Sarah Hughes (s.hughes@marlab.ac.uk)	FRS (Fisheries Research Services), Aberdeen, UK
8&9	North Sea	55, 56	Helgoland Roads – Coastal Waters – German Bight, North Sea	Karen Wiltshire (kwiltshire@awi-bremerhaven.de)	AWI/BAH (Alfred-Wegener-Institut / Biologische Anstalt Helgoland), Germany
8&9	North Sea	57	Section average, Felixstowe to Rotterdam (52°N)	Stephen Dye (stephen.dye@cefas.co.uk)	CEFAS (Centre for Environment Fisheries and Aquaculture Science), UK
8&9	North Sea	58	Sea Surface Temperature – North Sea Average	Peter Loewe (peter.loewe@bsh.de)	Bundesamt für Seeschifffahrt und Hydrographie, Germany
9b	Baltic Sea	59, 60	Baltic Proper, East of Gotland, and observed ice extent	Karin Borenas (karin.borenas@smhi.se)	Swedish Meteorological and Hydrological Institute, Sweden
9b	Baltic Sea	61, 62	Stations LL7, BO3 and SR5	Pekka Alenius (pekka.alenius@fimr.fi)	FIMR (Finnish Institute of Marine Research), Finland
10	Norwegian Sea	63, 64, 65	Svinøy, Gimsøy, and Sørkapp Sections	Kjell Arne Mork (kjell.arne.mork@imr.no)	IMR (Institute of Marine Research), Norway
10	Norwegian Sea	67, 77	Ocean Weather Station Mike – 50m	Svein Østerhus (Svein.Osterhus@gfi.uib.no)	Geophysical Institute, University of Bergen, Norway
11	Barents Sea	68	Fugløya to Bear Island Section, Western Barents Sea (Atlantic Inflow)	Randi Ingvaldsen (randi.ingvaldsen@imr.no)	IMR (Institute of Marine Research), Norway
11	Barents Sea	69	Kola Section, Eastern Barents Sea	Oleg V. Titov (titov@pinro.ru)	PINRO (Knipovich Polar Research Institute of Marine Fisheries and Oceanograph), Russia
12	Greenland Sea and Fram Strait	70	Greenland Sea section West of Spitsbergen, 76.5°N	Waldemar Walczowski (walczows@iopan.gda.pl)	IOPAS (Institute of Oceanology Polish Academy of Sciences), Poland
12	Greenland Sea and Fram Strait	71, 75	Greenland Sea section, 75°N	G. Budeus (Gereon.Budeus@awi.de)	AWI (Alfred Wegener Institute for Polar and Marine Research), Germany
12	Greenland Sea and Fram Strait	72	Fram Strait Section	A. Beszczynska-Möller (abeszczynska@awi-bremerhaven.de)	AWI (Alfred Wegener Institute for Polar and Marine Research, Germany
12	Greenland Sea and Fram Strait	74	Convection depths in the Greenland Sea	G. Budeus (Gereon.Budeus@awi.de)	AWI (Alfred Wegener Institute for Polar and Marine Research, Germany